

TECHNICAL REPORT 97-012

**OPTIMIZING LEARNING
COST-EFFECTIVELY
USING TECHNOLOGY**


NOVEMBER 1997

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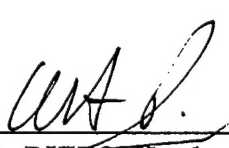
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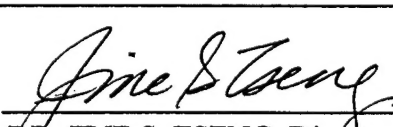
Prepared for:

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Report Documentation Page			Form Approved OMB NO. 074-0188	
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1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE 12/15/97		3. REPORT TYPE AND DATES COVERED Final Report
4. TITLE AND SUBTITLE OPTIMIZING LEARNING COST-EFFECTIVELY USING TECHNOLOGY (U)			5. FUNDING NUMBERS	
6. AUTHOR(S) John Leddo Dennis Buede Victor Valladares Jim Kolodziej Sean Beary				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Research Development Corporation 2875 Towerview Rd., Suite A-4 Herndon, VA 20171			8. PERFORMING ORGANIZATION REPORT NUMBER Technical Report 97-1	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Naval Air Warfare Center Training Systems Division 12350 Research Parkway Orlando, FL 32826-3224			10. SPONSORING / MONITORING AGENCY REPORT NUMBER Technical Report 97-012	
11. SUPPLEMENTARY NOTES Work performed under contract N61339-96-C-0106				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited			12b. DISTRIBUTION CODE A	
13. ABSTRACT(Maximum 200 Words) <p>The present paper reports a methodology and supporting tool for optimizing the use of multimedia technology to support training. Our goal is to support recent efforts to move training from schoolhouses to technology to save money and make training more readily available to sailors. Because technology development represents a huge investment, formal methods are needed for optimizing resources to meet training needs cost effectively. This includes supporting tradeoff analyses when sufficient resources are not available for the preferred technology option.</p> <p>We identified two Navy training technology scenarios. The first is developing technology for new training requirements. The second is converting lecture-based courses to technology-based. Accordingly, our project focused on both. First, we developed a methodology for selecting media to meet training requirements. This was supplemented by methods for projecting costs and benefits for selected media. Second, we developed a tool to estimate costs associated with course conversion.</p> <p>In order to be responsive to Navy needs, we established a relationship with the Chief, Naval Education and Training (CNET). Their most pressing need was course conversion. Therefore, we tested our tool on a CNET-supplied course using their costing data. The results of the tool's analyses matched CNET's own.</p>				
14. SUBJECT TERMS Training, Multimedia Technology, Training Delivery Assessment Model Cost Benefit Analysis			15. NUMBER OF PAGES 62	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Distribution Unlimited	

ACKNOWLEDGMENTS

We are especially grateful to Dr. Robert Breaux of the Naval Air Warfare Center, Training Systems Division, for his guidance and mentorship throughout the project. His scholarly input helped us to focus the project so that it would be more responsive to Navy needs. We are grateful to Mr. Terry Halvorsen of the Command, Naval Education and Training (CNET) for being our point of contact with that organization and arranging for us to focus our efforts on problems of interest to them. We also wish to thank him for arranging for us to speak with other representatives of that organization to understand their needs better. We wish to thank Dr. Bill Terrell of the Naval Air Warfare Center, Training Systems Division for helping us to draw connections between our work and the Training Delivery Assessment Model (TRADAM), thereby increasing the consistency between our respective approaches while giving us input as to how we could add value to existing Navy efforts. We wish to thank Dr. James Young of the Naval Air Systems Command, PMA 205-3 for his input as to the needs of the Navy training community.

EXECUTIVE SUMMARY

The present paper reports work on a Small Business Innovation Research Phase I project to develop a methodology and supporting tool for optimizing the use of multimedia technology to support training. The motivation behind this project comes from the recent trend to move training from traditional schoolhouses to technology so that costs can be saved and training can be made readily available to sailors when needed. Because the development of training technology represents a huge investment, there is a need for formal methods to analyze how to make best use of training resources so that training needs can be met in the most cost-effective manner. This includes supporting tradeoff analyses in cases where sufficient resources are not available to support the training community's "wish list" for technology.

In working with the Navy on this project, we identified two scenarios in which training technology is developed. The first is in developing technology for new training requirements where a comprehensive analysis must include developing the learning objectives and content as well as, selecting the right medium and developing the technology. The second scenario is converting current lecture-based courses to technology-based. The latter is an immediate need, the former an ongoing, long term need.

In order to be responsive to the needs of the Navy training community, we established a relationship with the Command, Naval Education and Training (CNET). Their most pressing need was course conversion. Specifically, their concern was whether technology could be used to save money over current schoolhouse instruction. Their analysis was governed by a goal of realizing sufficient cost savings such that these savings would pay for the conversion process within five years.

Based on the two identified needs (course conversion and development of technology for new training requirements), our project focused on two broad tasks. First, we developed a methodology for translating training requirements into the technologies that could meet those requirements. This was supplemented by methods for estimating projected costs and benefits associated with different technology options so that resources could be allocated to maximize training benefits at the lowest possible cost. Second, we developed a costing tool to estimate costs associated with converting courses to technology-based media. This tool was developed in conjunction with CNET. The tool was tested on a course that CNET was considering converting to technology-based delivery. Costing data used by the tool was supplied by CNET. The results of the tool's analyses on course conversion costs matched CNET's own.

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1.0 INTRODUCTION

There is strong pressure to move training from the schoolhouse to the field. The pressures to do so are twofold. First, in the light of declining Department of Defense budgets, there is a desire to reduce training costs. Second, moving training to the field offers greater local control so that training may be delivered "just in time" and more tailored to unit and individual sailor needs.

Technology is expected to play a significant role in this process. Technology can deliver training at reduced manpower costs and can be disseminated widely. Often technology can deliver training more effectively than traditional methods. Multimedia clearly offers a tremendous opportunity to create learning environments that are richer and much more realistic than traditional print-based media. In order to optimize the use of training media to promote learning, a methodology is needed to conduct a cost-benefit analysis that evaluates the costs of developing and using different technologies against the training benefits (e.g., increased learning or decreased time to train to criteria) these technologies produce based on the tasks and types of knowledge being taught.

We note that there are two major scenarios under which training technology may be developed or adopted. The first is when existing schoolhouse-based courses that need to be converted to technology-based courses so that they can be moved to the field or otherwise delivered in a more cost-effective manner. According to Vice Admiral Tracey, who is Chief of Naval Education and Training (CNET) and Director of Naval Training, a major effort within the Navy training community over the next few years will be using technology to move training from the schoolhouse to the field (1997). In these cases, training objectives are already well defined and course content is developed.

The second major scenario involves developing training systems for new weapons systems and other platforms from which sailors will be required to train. In such cases, the training requirements need to be developed along with the training material.

1.1 Needs from the course conversion perspective.

We have discussed with Dr. Jim Young of Naval Air Systems Command (NAVAIR), PMA 205-3 his view of what the needs of a multimedia training technology selection tool would be from the NAVAIR perspective. Below is our understanding of the points he made (we apologize if we misunderstood his points and therefore inaccurately relay them here).

According to Dr. Young, NAVAIR's immediate need is to support CNET in its course conversion process. He described this process as follows. A program manager at CNET needs to determine whether a course will be converted from lecture to technology-based. Any tool must help with a decision of either; keep as is, convert to Computer-Aided Instruction (CAI) or Interactive Courseware (ICW). The analysis here must justify the conversion so it can be pushed through the acquisition process. CNET stated a goal of a return on investment that breaks even within five years to justify the acquisition. After the conversion process is done, measures of

effectiveness are taken. The measures of effectiveness address the question of whether CNET gained anything to justify the conversion.

The above discussion illustrates the importance of cost projections and cost accountability in these analyses. It is clear that CNET makes its case for course conversion based on whether it can show cost savings by using training technology sufficient enough to pay for the course conversion within a five year period. Measures of effectiveness also center on evaluating whether the projected cost savings prior to the conversion actually occurred.

1.2 Needs from the new training technology requirements perspective.

Often a new system is developed or some other impetus that generates a training requirement. Unlike the immediate need for course conversion described in section 1.1, this is a long term requirement. In such cases, not only do cost considerations come into play, but it is also important to insure that the technology developed will adequately meet the training requirement for the intended trainee population. Here, there typically will not be present an existing, proven course that meets the learning objectives; therefore, the technology selection and development process is more complex. Media selection needs to be justified on the basis of its adequacy for the job. Also, as technology provides new and additional media for use in training, the number of options available will also increase.

Here, we argue a more formal approach may be required for media selection than is used in the typical course conversion process. The Navy has recently developed a Training Delivery Assessment Model (TRADAM) that step members of the training community through the process of developing courses, selecting media, assessing effectiveness, etc. TRADAM is too extensive to review in its entirety here. In section 3.1, we discuss our own framework and the parallels that it has to the TRADAM. In doing so, we spell out features of both frameworks.

1.3 Summary of Phase I accomplishments

There were four notable accomplishments on the Phase I effort. These were:

1. Conduct a literature review to determine the effectiveness of training technologies
2. Develop a framework for analyzing training requirements so they can be matched to training technologies for which a cost-benefit analysis can be performed
3. Develop a costing tool for course conversion analysis
4. Test the tool on courses provided by CNET

2.0 A LITERATURE REVIEW OF THE EFFECTIVENESS OF TRAINING TECHNOLOGIES.

In order to address the long term need of determining which technology to use to meet which training requirement, it was important to determine whether there was an empirical basis to the claim that technology-based training could meet training objectives at all. We conducted a review of the literature to make this determination. While we found that there was variability

across studies, there was a clear and consistent base of evidence that suggested that technology-based instruction outperforms traditional print-based and classroom instruction in terms of leading to increased student learning or decreased learning time. This suggests that technology can be used to supplement or replace traditional means of education, thereby meeting training objectives while moving training to the sailor at cost savings.

We summarize some of the results of our initial literature review, which will form the basis of the general population norms we will use to project training benefits in our framework. We note that most studies compare technology-based instruction to Print-Based Instruction (PBI). The type of dependent measure reported is mean improvement in test performance measured in Standard Deviations (SD). In other words, if a result of .5 SD is reported, it means that the experimental (technology group's) mean performance was .5 standard deviations higher than the mean performance of the control group. An improvement of .5 SD is roughly equivalent to increasing the mean performance (50th percentile) of students in the experimental condition to that of students at the 69th percentile in the control condition.

In our literature review, we found that metaanalysis studies were by far the more useful sources of information due to the fact that they compared different multimedia technology effects with the more traditional classroom delivery. The effects of multimedia varied between grade and age levels. We organized these into five categories:

- Effects of Multimedia on Elementary and Intermediate School Students
- Effects of Multimedia on High School Students
- Effects of Multimedia on Educationally Disadvantaged Students (K-12)
- Effects of Multimedia on College Students
- Effects of Multimedia on Adult Education (e.g. military education)

Several studies (Ryan, 1991) performed on the Achievement Effects of Microcomputer Applications in Elementary School Students, showed that the average student in the treatment group exceeded the performance of 62% of the students who were in the control group. It was also found that students in the treatment groups responded enthusiastically to computer instruction. Another study, testing the effects of peer interaction on computer-based math instruction, found that students learn more effectively in groups than alone (Hooper, 1992). The effects of peer interaction on achievement and efficiency on elementary school children were also observed. The results showed that both achievement and efficiency are highest for high-ability homogeneously grouped students and lowest on average-ability homogeneously grouped students. Bracey (1993) studied the effectiveness of hypermedia in elementary school education. The study found hypermedia to be more effective on a long term basis rather than on a short term basis (study lasted three years). One particular study done on intermediate school instruction tested the effects of word processing on student writing in a high computer access environment. In this study it was discovered that students experienced in using word processors were able to produce better quality writing than subjects who used paper and pencil (Owston, Murphy, et al., 1991).

The effects of multimedia in high school instruction focused mainly on two subjects: Science and Mathematics. Computer Assisted Interactive Video Disk Instruction (CAIVDI) proved to be effective in science because it offers a delivery system that permits students to freely investigate topics (e.g. chemical reactions) without the financial burden of paying for chemical supplies. Another finding was that multimedia can actually adapt to the students learning style as long as the student uses a well-designed multimedia environment (Hoffer, Rodke, et al., 1992). The use of simulation software also proved to have interesting results. A comparison of Computer Assisted Learning (CAL) plus classroom and laboratory instruction versus classroom-lab work (alone) showed that the experimental group achieved a significantly higher mean score on academic achievement post test (Lazarowitz, Huppert, 1993). There were no significant differences within groups by gender (in experimental or in control groups). Another type of simulation software tested was Interactive Dissection (IVD) Simulation. In this case IVD simulation was used in two different ways: as a substitute for dissection and as a preparation tool to dissection. IVD simulation as a substitute proved to be at least as effective as actual dissection in promoting student learning. The use of IVD simulation as a preparation tool was more effective to students than no preparation at all. IVD was also better than viewing a videotape as preparation to dissection (Kinzie, Strauss, et al., 1993).

The effects of embedding generative cognitive strategies in science software was tested on 10th grade level students. The experimental group performed better on post tests than the control group. The study showed that embedding cognitive strategies into science software proportionately benefits low verbal learners more than high verbal learners (Barba, Merchant, 1990).

Distance learning has also been an important topic in the use of multimedia. A student satellite-delivered course testing the student achievement and attitude found that indeed this form of delivery can be more effective than standard instruction (Martin, Rainey, 1993).

In the instruction of mathematics at the high school level the focus was the influence of problem solving software on the attitudes of students. Computer Augmented Instruction (CAI) was the subject of interest in this case. Students using this type of multimedia achieved more gains on a test problem solving ability than students not using CAI. Furthermore, they had more positive attitudes about themselves when studying mathematics. Also, female students showed an interest in wanting to work in math related jobs in their futures (Funkhouser, Djang, 1993).

Another comparison made on high school student instruction was the use of Computer Based Instruction (CBI) with Print Based Instruction (PBI). The use of CBI showed significantly higher motivation and higher scores in immediate recall over students learning from PBI (Yang, 1991-1992).

As we can see, multimedia has a positive effect on students from grade levels K-12. However, an interesting question is whether multimedia is sufficiently diverse to be helpful and have a positive impact on other cases such as educationally disadvantaged students. An investigation of the use of CBI for providing remediation to this student population showed significant increases in both reading and math performance (such increases showed to be

educationally meaningful). Special education students benefited most from CBI use at all grade levels, and remedial and general education students benefited least at most grade levels (Swan, Guerrero, et al., 1990).

The effectiveness of CBI at the college level had very favorable results towards the achievement of students in the classroom. CBI raised student exam scores by 0.26 SD's in the average study. CBI effects were somewhat lower in the hard and nonlife sciences than in social sciences and education. CBI also produced small but, positive changes in college student attitudes toward instruction and computers. Furthermore, it was found that CBI substantially reduced the amount of time needed for instruction at the college level (Kulik & Kulik, 1986). Another multimedia technology that was investigated was CAIVDI. The study focused on the effects of the use of CAIVDI on learning style preferences, attitude and GPA on the learner. There were three conclusions concerning learning style: a) Students who perceived CAIVDI as less creative desired more mobility while learning and were less persistent overall; b) students who were more comfortable with the computer had less need for mobility and were more persistent; and c) students who perceived the computer as functional had less need for mobility while learning. There was no significant relationship found between learning style preferences and learning achievement. One significant relationship between attitudes toward CAIVDI and learner achievement was that the student that was more comfortable with the computer scored higher on the posttest. GPA also seemed to have a correlation with attitude towards the use of multimedia. Students with higher GPA were more motivated and responsive towards CAIVDI (Billings, Cobb, 1991).

According to analytical reviews, multimedia use in adult education such as interactive Videodisc Instruction (VDI) showed that overall, VDI improved achievement by 0.5 SD's over less interactive, more conventional approaches to instruction. The improvement is roughly equivalent to increasing the achievement of students at the 50th percentile to the 69th percentile. In Military training, and improvement of 0.38 SD's was observed across several studies (roughly an increase from 50th percentile to 65th percentile). In higher education, an improvement of .69 SD's was observed (50th to 75th percentile achievement). Interactive VDI was more effective when the interactive features of the medium were utilized (Fletcher, 1990). We also found analytical reviews on the effectiveness of Computer-Based Adult Education. Studies showed that Computer Based Education (CBE) usually has positive effects on adult learners. CBE raised the examination scores of such students by 0.42 SD's on the average study (a statistically significant effect). Again, it was found that CBE substantially reduced the amount of time needed for instruction. Reliable conclusions could not be reached about affect or long term cognitive effects of CBE because of the small number of studies that investigated such effects (Kulik, Kulik, et al., 1986).

A few studies have looked at time to train as a dependent measure rather than training improvement. This dependent measure is of greater interest to training organizations such as CNET. Their view is that the Navy already does an adequate job training its personnel. However, reducing training time without sacrificing training quality will enable cost reductions. Orlansky and String (1979) found that computer-based instruction resulted in a 30% reduction in

time to train over traditional methods. Fletcher (1991) also reports a 30% time to train reduction for multimedia technology as well as 30%-40% reduction in training costs.

CNET and others have expressed concern over the variability of these results and that such variability may make it difficult to make reliable predictions about how effective a given technology will be. We agree that such variability is problematic. However, the consistent positive effects shown by these studies suggest that one could be reasonably confident in a positive effect, even if the size of that effect had to be represented by a range of outcomes rather than a precise outcome. While it is an empirical question, we believe that more stable results may be possible if an organization collects data on its own student population for its own courses and technologies used. In section 3.5.1, we discuss the use of Bayesian updating techniques to combine organization-collected data with more general data reported in the literature.

The above results do point to a significant gap in the literature. The types of studies reported in the literature focus on the use of different types of technology in training subject areas. There is tremendous variability within a technology medium such as Interactive Videodisk as well as a subject area such as mathematics. This could also explain the variability in the results observed. The studies we reviewed did not focus on the components of the technology (e.g., video vs. audio) or the type of problem solving skills (e.g., critical thinking vs. formula execution) being taught in the subject area to see whether there were sharper relationships between them.

The primary purpose of the reported work was to develop a framework to prescribe what types of problem solving skills would be best taught by what types of technology. The above cited research addresses the general question as to whether technology can lead to improved or quicker learning when used instead of Print-based Instruction or classroom instruction. The remainder of the report outlines a framework for decomposing training requirements into the underlying knowledge and skills to be taught and matches these to the technology components that are hypothesized to be best suited for training these knowledge and skills.

3.0 DEVELOP A METHODOLOGY FOR OPTIMIZING THE COST-BENEFIT RATIO OF USING MULTIMEDIA IN TRAINING.

The main activity in Phase I was to begin the development of a methodology for optimizing the use of multimedia for training both in terms of training benefit and costs. Since the start of the Phase I project, the Defense Standards Workgroup has developed TRADAM to serve as a guide for members of the training community to develop and deliver technology-based training. This development caused us to refocus our efforts to be more compatible with directions the Navy is taking in these areas. Fortunately, our framework and that described in TRADAM are highly compatible.

TRADAM is a more comprehensive process than what we developed in Phase I. Therefore, in demonstrating how our project is designed to complement and enhance TRADAM, we will only focus on those portions of the TRADAM that are relevant to our Phase I framework. We do note, however, that because of our interest in supporting the PMA 205-3 stated requirement of

supporting CNET's course conversion efforts, our discussions on costing (particularly in describing the tool we will develop) and the tradeoff techniques are likely to be more detailed than what is discussed in TRADAM.

3.1 Translation of course objectives into knowledge and skills requirements for training.

The first step in the development of a training requirement is to develop a set of course objectives. These are typically driven by tasks that the Navy (or other organization) expects their personnel to perform. Our methodology assumes that this step has already been performed. This is one that is covered by TRADAM but is not part of our framework as the Phase I project does not offer any innovations in this area.

The next step in the TRADAM process is to develop the knowledge, skills and attitudes necessary to perform these tasks. The framework we present for doing this focuses on knowledge and skills, but not attitudes. Given the comprehensiveness of TRADAM, we have made a deliberate decision to focus on those portions which we feel we have mature frameworks and approaches to minimize risk and position ourselves for success in the project.

Our framework for decomposing tasks into underlying knowledge and skills is based on Research Development Corporation's Integrated Knowledge Structure or INKS framework. INKS is based on knowledge representation formalisms found in the cognitive psychology and cognitive science literatures.

3.1.1 The INKS framework.

Each task a person may be expected to perform has associated problem solving knowledge. The goal of this step is to link Navy tasks to that underlying knowledge. Research indicates that problem solving knowledge is diverse and well integrated (Laskey, Leddo, and Bresnick, 1989; Leddo et al., 1990). People have a variety of problem solving strategies at their disposal and can apply them as called for by the situation. These strategies are functional in nature and are oriented toward the goals and objectives that characterize the person's job.

A central theme in knowledge is its functional orientation. Knowledge is centered around goals. As a result, any modeling of knowledge and implications derived for instruction must take goals into account. In fact, research by the Yale University Cognitive Science Group (cf., Galambos, Abelson and Black, 1986) suggests that goals play a powerful role in organizing people's knowledge in general. This point is important because we believe that much of the high level decision making is more goal driven than procedural. While researchers such as Anderson (1982) have argued that expert knowledge is characterized by procedural knowledge, Leddo et al. (1990) find that true expertise is characterized by goal and causal knowledge while procedural knowledge actually characterizes experienced nonexperts (who are more advanced than novices but are not true experts). The research described above focuses on the behaviors exhibited by people. We must now look at how to translate knowledge of these behaviors into knowledge components that could be used for identifying training technologies that could teach them.

In the cognitive science and psychology literatures, several frameworks have been proposed as models of knowledge. These schemes tend to address different types of knowledge. For example, scripts (Schank, 1982; Schank and Abelson, 1977) are used to represent goal and planning knowledge that is used in fairly routinized environments. Scripts are generalized sequences of steps used to achieve a goal. Script-like schemas can also be used to integrate bodies of knowledge into a larger framework.

Scripts are organized around goals people wish to achieve. Scripts contain plans for achieving those goals. In addition to the planning information, scripts contain information such as entry conditions (which state when the script is appropriate to use), outcomes (the result of executing the plan), actors (the people involved in the plan), and props (physical objects that are instrumental in plan execution).

Knowledge about data patterns and how objects are organized together can be represented by object frames (c.f., Anderson, 1980; Minsky, 1975). Frames are very much like scripts in that they are expectancy-driven organizers of knowledge. We conceptualize scripts as focusing more on goal and plan-related knowledge while frames organize collections of objects. Frames can also be distinguished from semantic nets (cf., Quillian, 1966) which tend to organize information about individual concepts (such information being referred to as the concepts "features") and relationships between them rather than collections of objects. For example, the configuration of a computer that is used in training may best be represented by a frame since it is a collection of system components and relationships among their physical locations while a single system component such as a hard disk may best be represented by a semantic net that describes its features (e.g., its storage capacity, access speed).

Knowledge about situation-specific procedures can be represented by production rules (cf. Newell and Simon, 1972). Production rules are expressed in the form "IF [antecedent condition], THEN [consequent action]", where antecedent conditions are situational conditions that determine when procedures are to be executed and consequent actions are the procedures executed under those conditions. Production rules are useful in both carrying out procedures (e.g., "If this step has been completed, then do this next step.") and also generating inferences (e.g., "If the following problem features are observed, then infer that this is an [X] type of problem."). Production rules can be distinguished from scripts in that scripts organize entire goal-driven plans, while production rules organize specific actions. Scripts can be viewed as collections of production rules much the way that frames can be viewed as collections of semantic nets.

Finally, causal and analogical reasoning can be captured by mental models (cf., de Kleer and Brown, 1981; Johnson-Laird, 1983; Leddo, Cardie and Abelson, 1987). In our framework, (Leddo, Cardie and Abelson, 1987), mental models are viewed as encoding the causal rationale for why a specific problem solving procedure is used. One of the factors that distinguishes the way experts solve problems from the way nonexperts do is the former's heavy reliance on mental models and the ability to use them to select an appropriate problem solving strategy to meet a set of objectives. We argue that mental models are key to teaching conceptual problem solving skills, because it is often knowledge of goals and causal relationships that are the key to developing solutions to novel or abstract problems. We also believe that mental models are, therefore, central to evaluating

situations and generating plans in situations that are novel and for which there are no preprogrammed procedures.

We have discussed five different representation frameworks (scripts, object frames, semantic nets, production rules, and mental models) for representing knowledge. As we mentioned above, people possess diverse knowledge that is richer than can be handled by any single framework. Leddo, Cardie and Abelson (1987) developed an Integrated Knowledge Structure (INKS) framework that combines these individual schemes. In the INKS framework, scripts serve as the general organizer of knowledge, linking plans and goals together. Production rules give situation-specific procedures to be executed given conditions that arise during the execution of a plan. Frames organize collections of objects that are utilized in the execution of plans while semantic nets organize features of the individual objects within a frame. Mental models provide the rationale for why procedures are executed and how they are instrumental in achieving objectives.

The INKS framework has received considerable testing in recent years. It has been tested empirically as a model of expert problem solving knowledge (Leddo et al., 1988; 1990); it has been used as a model for an AI problem solving system (Leddo, Cardie and Abelson, 1987), as the basis for developing knowledge elicitation tools (Leddo et al., 1987; Leddo and Cohen, 1989; Leddo et al., 1992; Leddo et al., 1995), and as the basis for intelligent tutoring systems (Leddo, Sak and Laskey, 1989; Leddo, Laskey and Vane, 1992; Leddo, Elliot and Woolf, 1994; Leddo, 1995a; Leddo and Kolodziej, 1996) and ITS authoring tools (Leddo, 1995b).

There is a rough correspondence between the INKS framework and the knowledge and skills described in TRADAM (where “knowledge” refers more to things people can report and “skill” refers more to an ability to perform, as in performing a task). Within TRADAM, there is an explicit distinction between the concept of “knowledge” and “skill”. Within INKS, there is not. This is because structures such as scripts and production rules can serve both purposes. A script can be used to report what knowledge is necessary to solve a problem and also embodies the actions necessary to carry out the plan. TRADAM refers to the following types of knowledge: facts, rules, procedures, discriminations, and problem solving. While the mapping to INKS is not one-to-one, there are strong similarities. For example, facts correspond to semantic and object frame knowledge depending upon whether the concept being learned is a single object or configuration of them. Rule learning (which in TRADAM refers to concepts that are connected to each other—such connections being reported by the rule) can either map to object frames if the rule is about how different semantic concepts group together or to production rules if the rule is about a set of procedures that go together. Procedures map directly to production rules. Discriminations span all the INKS types. One can make discriminations across semantic and object frames based on their features, across production rules based on their antecedent conditions, across scripts based on their goals and entry conditions, and across mental models based on their causal elements. Problem solving knowledge maps to either scripts or mental models depending upon the level of abstraction. The table below summarizes these correspondences:

TRADAM Knowledge Elements	INKS Knowledge Elements
Facts	Semantic Nets, Object Frames
Rules	Object Frames, Production Rules
Procedures	Production Rules
Discriminations	All Structures
Problem Solving	Scripts, Mental Models

Table 1. Correspondences between TRADAM and INKS Knowledge Elements

There are a variety of skills that are reported in TRADAM. These include perception, gross motor skills, readiness, mechanism, continuous movement, adaptation, and origination. Again, there is a mapping to the INKS framework. Perception relates to correct encoding of the situation. This corresponds to invoking the correct situation features or entry conditions to invoke the correct knowledge structure. Therefore, any INKS structure is applicable. Similarly, readiness refers to a state of being ready to take action. This pertains to having the appropriate INKS structure active that is necessary to the situation. Adaptation and origination refer to modifying and creating, respectively, new skills to meet a new situation. Within INKS, mental models are used by people to create or adapt new skills (Leddo et al., 1990). Gross motor skills, mechanism and continuous movement relate to scripts and production rules where the level of precision, movement continuity, etc. are spelled out by the structures. Again, we present the similarities between the frameworks in the table below:

TRADAM Skill Elements	INKS Skill Elements
Perception	All, based on features or entry conditions
Gross Motor Skills	Production rules, Scripts
Readiness	All, based on activation of correct structure
Mechanism	Production rules, Scripts
Continuous Movement	Production rules, Scripts as specified
Adaptation	Mental models
Origination	Mental models

Table 2. Correspondences between TRADAM and INKS Skill Elements

3.1.2 Use of INKS to operationalize tasks to be trained into learning objectives.

Both TRADAM and our framework call for the training tasks to be operationalized into learning objectives. The basis for both is to use the knowledge/skill framework (in TRADAM's case it would be knowledge/skill/attitude). This can be accomplished by having a trainer and a Subject Matter Expert (SME) construct an INKS model of the tasks to be trained. Ordinarily, a

trained knowledge engineer would take part in this process. In order to facilitate this process without the use of a knowledge engineer, tools could be created to prompt trainers and SMEs create an informal INKS model of the tasks. We use the term "informal" because the rigor necessary to build an expert system (which is a typical application of knowledge engineering) does not apply here. Rather, the key is to spell out the knowledge and skills to be trained in sufficient detail so that a training model can be developed around it. In order to help the process of developing this INKS knowledge, we have developed a knowledge elicitation technique called Cognitive Structure Analysis (CSA). This technique can be used without the aid of an automated tool. We describe the technique below.

CSA's method of querying a person is driven by both structural and content considerations of the knowledge structures in the INKS framework. For example, scripts not only describe what events will happen in a context (the content knowledge), but also their sequence, their importance, etc. (the structural knowledge). Therefore, a trainer wishing to develop script-based knowledge associated with training tasks would ask about the goals being addressed, the conditions under which the script is used, the subgoals to be accomplished, the steps to be taken and the outcome that results when the script is complete. An automated tool to assist with this process would offer prompts to the user for each of these components.

Similarly, production rule knowledge consists of procedures to follow and the antecedent conditions that trigger those procedures. The system could prompt a user to answer questions about antecedent conditions and procedures as well. Semantic knowledge consists of concepts, their features or attributes, instances (examples) and parent concepts. Object frames are configurations of these concepts. Finally, mental models focus on how causal elements (e.g., things that have force) interact within a context or domain (that could be defined by semantic features). CSA queries can be constructed for each type of knowledge. An automated tool would present users with queries for each of these and help the trainer organize the knowledge in a tree or learning objective hierarchy as is used in the TRADAM process.

3.1.3 An example of this process.

In order to demonstrate our methodology in action, we will use a running example. The running example is designed to be illustrative rather than complete or even accurate in terms of the content described. We use as an example that the trainee will be able to identify an enemy aircraft as friend or foe. The first step is to develop an INKS of this.

The semantic knowledge that pertains to this may be the cues that one has to make this determination. For illustration purposes only, we will assume that the cues are:

- a) whether the aircraft is firing at you;
- b) whether his Identification Friend or Foe (IFF) transponder signals friendly;
- c) what altitude the aircraft is flying at;
- d) what speed the aircraft is flying at;
- e) whether the aircraft is flying through a safety corridor, where each of these cues may be represented semantically as an attribute of the aircraft to be identified.

Procedures may relate to inference rules that a sailor might use to make the IFF determination. These may include:

- a) If the aircraft is firing at you, treat as enemy.
- b) If the aircraft is not firing at you and its IFF transponder signals friendly, treat as friendly.
- c) If the aircraft is not firing at you and its IFF transponder has no signal, then use a two out of three rule for the remaining cues to determine whether to treat aircraft as friend or enemy (assuming that there is a correspondence between altitude, speed and safety corridor and what friendly vs. enemy planes would do).

Schema may include different battle sequences that may help make a determination on how to treat the remaining cues. For example, aircraft tend to fly at low altitudes as they make a bombing run and higher altitudes en route and on the way back to avoid enemy air defense. Therefore, if the sailor is near a strategic target and an aircraft is approaching at low altitude, it may match the cue of an enemy aircraft making a bombing run.

While we are using this particular example, we wish to point out that not all learning objectives will require every type of INKS knowledge and skills.

3.2 Translation of knowledge and skill requirements into sensory stimulus requirements

Once the operationalization of the learning objectives into an INKS-based format is completed, the INKS-operationalized learning objectives are translated into sensory stimulus requirements. This step is also included in the TRADAM process. Our process is less comprehensive. The goal of this step is to form the basis of determining what training environments and experiences will be necessary to train the appropriate knowledge and skills.

In our framework, the judgment of what sensory stimulus requirements are necessary to train particular knowledge or skills must be made by the trainer or subject matter expert. It is impractical to try to develop a generalized tool that is able to make this translation itself. However, one could provide a template and set of dimensions that are useful to categorize the sensory stimuli. We illustrate our approach with three dimensions: sensory modality (e.g., visual, auditory, tactile); fidelity; and configuration (e.g., is there spatial grouping of stimuli, temporal sequencing or are stimuli presented independently of each other (which we define as "no configuration"?)).

The trainer would then go through each INKS component and make these determinations. The table below illustrates this process for the example above (again keeping in mind that this is for illustration purposes only and the example may not be factually accurate).

Cue	Modality	Fidelity	Configuration
Firing	Visual	Low	Spatial Grouping
IFF	Visual	Low	N/A
Transponder			
Altitude	Visual	Low	Spatial Grouping
Speed	Visual	Low	N/A
Safety Corridor	Visual	High	Spatial Grouping and Temporal Sequencing

Table 3. Sensory Stimulus Requirements for Cues to be Taught

3.3 Development of a training strategy

The next step in our methodology is to develop a training strategy to meet the learning objectives given the types of sensory experiences required. We also take into account trainee population characteristics as we will explain shortly. We consider this part of our model to represent an enhancement to the TRADAM process. TRADAM does describe the different types of training environments and the need to take trainee characteristics into account. However, TRADAM is not formulaic in how this process should occur.

We do confess that our approach, while based on both cognitive theory and some empirical findings is still largely theoretic. We recognize that this is likely to be the weak link in our chain and the one with the largest risk factor. However, since our process is designed to be modular, this step can be omitted or a trainer can arrive at a training strategy based on experience and judgment. Therefore, the fact that our hypotheses about how to accomplish this step may be insufficiently supported to instill confidence in a user following our recommendations is not fatal to the overall methodology described here in section 3.

The goal of this step is to arrive at a training strategy that specifies how much of different types of training should be provided to trainees to have them master the learning objectives. This then will be used to specify what technologies will be used. We have three dimensions along which the training strategy will be developed. These are:

1. The training environment (e.g., type, fidelity);
2. the degree of instructor support (human or artificial) vs. self-direction;
3. whether training is administered individually or as a team.

Training environment types include such things as live practice, simulator-based practice (constructive or virtual), text-based instruction, lecture, etc. Fidelity relates to how close the training environment must be to the actual experience in order to achieve the desired level of training.

We use the sensory stimulus requirements developed in the section above to make determinations regarding the training environment. Degree of instructor support required is a function of both the task to be trained and the characteristics of the trainees to be taught the task. Whether training is administered individually or as a team is a function of the task (e.g., is it inherently a team exercise or an individual one?). While training for tasks performed by individuals can often be delivered simultaneously to a group of people, the technology itself would only need to provide instructor support at the individual level not the team level. On the other hand, training for tasks performed by teams would require instructor support at the team level.

Because trainee population characteristics will impact the ideal learning environment, we outline three relevant dimensions here:

1. Aptitude
2. Experience
3. Learning style

In general, aptitude has been found to affect training environment and amount of instructor support required. Low aptitude students benefit from higher fidelity environments and require greater instructor support than high aptitude students that seem to learn on their own and regardless of how information is presented.

Experience has two effects on the training strategy. First, it determines what learning objectives actually need to be trained. If trainees have the required skills, then the training strategy can omit them. For this reason, the TRADAM process actually has this step before the analysis of sensory stimulus requirements (and could be performed before in our methodology if desired). Second, highly experienced students often show similar effects with regard to fidelity and self-directed instruction as high aptitude students (probably the two are typically correlated in practice), while inexperienced students typically show similar effects as low aptitude students.

A person's learning style is typically characterized by the factors in which he learns best. The most common dimension along which learning style is operationalized is sensory modality by which subject matter is presented. In cases where the same learning objective can be taught using multiple sensory modalities, then the trainer can opt for the one that matches trainee learning style or give the trainee the option to select which mode he/she will learn by. Our assumption is that the three trainee population characteristics that we have described would be input by the trainer, if such information is available. We understand from our work with CNET that the Navy gives its recruits batteries of tests that measure a variety of the recruits' characteristics. Certainly, if not provided by other sources of information, trainee experience levels can be estimated from the level of the course and the required prerequisites.

In developing a training strategy, two approaches are possible: The first, is to assume a mix of training environments (e.g., a portion of a course will be converted to technology-based). In this case, the trainer can try to optimize the mix to produce the best training benefit or the lowest

cost. The second approach, is to assume that only one training environment will be used. In this case, the trainer must look for the minimum environment that meets all the learning objectives.

We now present some illustrative guidelines for mapping sensory stimulus requirements to training environments. We present a continuum of nonclassroom-based instructional environments. Each are intended to represent a higher level of fidelity and can accommodate the ones that precede them. The environments (while illustrative and not exhaustive) are:

1. Text
2. Graphics, audio, haptic
3. Constructive simulation
4. Non-immersive virtual simulation, video
5. Immersive simulation
6. Live practice

Given these environments, we present a hypothesized table of what the minimum training environment would be for a learning objective of a specified sensory modality, fidelity level, and configuration.

Low Fidelity Sensory Stimulus Requirement

Sensory Modality	No Configuration	Spatial Configuration	Temporal Configuration
Sensory Independent (i.e., can be presented via any sensory modality)	All Environments	N/A	All Environments
Visual	Graphic	Graphic	Graphics Sequence
Auditory	Audio	Stereo	Audio Sequence
Tactile (i.e., learning by touch)	Haptic	Multi-haptic	Haptic
Kinesthetic (i.e., learning by feedback of bodily position)	Immersive Simulation	Immersive Simulation	Immersive Simulation

Table 4. Minimum Training Environment for Low Fidelity Cues based on Sensory Modality and Configuration

High Fidelity Sensory Stimulus Requirement

Sensory Modality	No Configuration	Spatial Configuration	Temporal Configuration
Independent	All Environments	N/A	All Environments
Visual	Graphic	3-D Graphic	Simulation, Video
Auditory	Audio	Stereo	Audio Sequence
Tactile	Haptic	Multi-haptic	Haptic
Kinesthetic	Live Exercise	Live Exercise	Live Exercise

Table 5. Minimum Training Environment for High Fidelity Cues based on Sensory Modality and Configuration

We wish to make some comments about the preceding tables:

1. First, in cases where the same environment appears in both low and high fidelity cells, the fidelity of the environment would be affected even if it is the same. For example, a single auditory stimulus may still be presented by audio regardless of whether the sensory stimulus requirement is high or low fidelity, but the fidelity of the audio would need to correspond to the fidelity requirements of the stimulus (i.e., a high fidelity sensory stimulus requirement would require high fidelity audio whereas a low fidelity sensory stimulus requirement would require low fidelity audio).

2. Second, the minimum environment requirements may change as technology changes. For example, we know of no immersive environments that provide high fidelity kinesthetic feedback. Therefore, we cite live exercise as the minimum configuration for those learning objectives that require high fidelity kinesthetic feedback. This technology may change in the future and the minimum training environment required would also change.

3. Third, there will be many cases in which the learning objective will have multiple sensory modalities. Each of which may require a different minimum training configuration. In cases where multiple training environments are possible, this analysis would specify what mix of training environments are needed. We stated earlier that the other possibility was when only one form of training environment will be used. In such cases, the minimum training configuration will be the highest training configuration that contains all of the sensory stimulus requirements.

3.3.1 Selecting training environments for the running example of IFF.

We now apply above analysis to our previous running example of training the IFF task. We repeat the previously shown table of the sensory stimulus requirements for the training of different IFF cues:

Cue	Modality	Fidelity	Configuration
Firing	Visual	Low	Spatial Grouping
IFF	Visual	Low	N/A
Transponder			
Altitude	Visual	Low	Spatial Grouping
Speed	Visual	Low	N/A
Safety Corridor	Visual	High	Spatial Grouping and Temporal Sequencing

Table 6. Sensory Stimulus Requirements for Cues to be Taught

Based on our hypothesized match of sensory stimulus requirements to training environments, we come up with the minimum training environment required to teach the use of each cue:

Cue	Minimum Training Environment
Firing	Graphic
IFF Transponder	Graphic
Altitude	Graphic
Speed	Graphic
Safety Corridor	Virtual Simulation or Video

Table 7. Minimum Training Environment for Cues to be Taught

As seen from the above table, much of the task can be trained using simple graphics. The cue of safety corridor requires a virtual simulation or video. Therefore, if multiple training environments are allowed, then a combination of graphics and simulation/video are possible and these could be constructed based on cost considerations. If only one format is allowed, then it would have to be virtual simulation or video to encompass the entire learning objective.

3.4 Development of technology requirements.

Once the learning environment is established, the next step is to determine what technology will be used to deliver the training. Here, multiple technologies are potential options as long as they deliver the capabilities required (e.g., CBT and the Internet can deliver graphics). We recommend that in cases where the trainer has the option to pick the medium/technology that multiple options are examined so that when costing is done and/or tradeoffs need to be made, there are multiple options to choose from to try to meet all the constraints. There may be cases where multiple media are selected as each might cost-effectively meet a portion of the training requirement. In cases where the medium or technology has been selected, then the training environment analysis will specify how to construct the technology, which in turn may help cost it out.

We adopt the general approach used by TRADAM in conceptualizing categories of training technology. These include such things as Interactive Courseware (ICW), Computer-Based

Training (CBT), Interactive Videodisk (IVD), Internet, Videoconferencing. For each technology, it is important to develop a matrix of what capabilities it has. These capabilities match both the training environment dimensions presented in the previous section (e.g., graphics, simulation, etc.) as well as the dimensions of instructor vs. self-guided and individual vs. group that is related to trainee population and task characteristics, respectively.

We are cognizant of the fact that training technologies themselves evolve with a general trend of increasing capability. For example, the Internet can present graphics and text and through recent developments, real time audio. Full motion video and virtual simulation are problematic, but with future advances in bandwidth, these may be possible. Therefore, a commercial implementation of our framework should include a database of evolving technology capabilities so that updates to the inputs used in our framework regarding available technologies can be made. For example, as new video cards are introduced, PC's are approaching the graphics power of high end graphics machines, but at substantially lower costs. These advances may have strong effects on what technologies are selected for training.

In the table below, we present some sample media and their current capabilities.

Technology	Maximum Training Environment Supported	Instructor support	Individual or Team Training
Print	Graphics	Low	Individual
CBT	Video	Medium	Individual
Distributed Interactive Simulation	Virtual Simulation	Low	Team
IVD	Video	Low	Individual
Video-teleconferencing	Video	High	Both
Internet	Graphics/Audio	High	Both

Table 8. Current Capabilities of Sample Media

As we noted above, these dimensions can change as technology changes. For example, intelligent tutoring system technology (cf., Greer, 1995; Leddo and Kolodziej, 1997) increases the power of CBT and DIS instructor support (i.e., the degree to which the technology can act as a surrogate instructor). As bandwidth width increases, the maximum training environment supported by the Internet will increase.

3.4.1 Selecting training technology for IFF task.

We can apply the above technology capabilities to the IFF task. IFF is a task performed by an individual. Depending upon the experience and aptitude of the trainee, it may require low

instructor support. For the purposes of this example we will assume this to be the case. The table below shows the technologies that would support training the IFF task.

Cue	Training Technologies
Firing	All
IFF Transponder	All
Altitude	All
Speed	All
Safety Corridor	CBT, IVD, Videoteleconferencing

Table 9. Technologies That Could Support Training Each Cue

3.5 Projection of costs and training benefits for each technology option

3.5.1 Projection of training benefits.

Training benefits can be measured in two ways: Increased learning, and time to train to a criterion. Ultimately, the computation of training benefit is an empirical determination that is made after the training is completed and the outcome is assessed. However, since the present project focuses on supporting decision making, projections of benefits should be made before training is done or the technology developed. In such cases, base rate data provides the basis for this projection. There are two sources of base rate data. The first, is to use data taken from the general population based on subject matter trained, technology used, and student population characteristics. The second, is to use the same data from the training organization. There is a tradeoff here.

We have reviewed the training technology literature and have found tremendous variability across studies that have been reported in terms of the benefits of the training technology. Therefore, we believe that the most reliable data will come from an organization's own practices and student populations. However, there tends to be less of this data. We recommend a hybrid solution that uses both general population base rate data and data collected from the specific training organization. In using general population base rate data, an organization should look for data that match, as closely as possible, their student population characteristics, subject matter, and technology used. These data form the initial projection of training benefit for using technology to train the organization's student population. Unfortunately, most empirical studies have focused on increased learning as a dependent measure rather than reductions in training time.

The base rate data should be supplemented by training data based on their own experiences using training technology. Since such data will be accumulated gradually, it should receive increasing weight as more data is collected compared to general population data collected over larger samples and larger numbers of studies. One method of implementing this gradual phasing in of organizational data with base rate data is through the use of Bayesian updating. The

standard Bayesian updating for parameters that vary from zero to one such as learning rate is based upon the Beta distribution. The Beta distribution is characterized by two parameters; the success rate and the number of trials, signifying the extensiveness of the empirical research. Each update then adds a new success rate and the number of trials associated with this data. These data are combined with the prior information to produce a posterior distribution. Each new update is added to all of the previous updates and the prior. As more and more data are accumulated, the posterior distribution becomes more and more peaked around the mean with decreasing variance.

Based on the literature review presented in section 2, we can project some training benefits for training the IFF task using different media. Note, that all numbers presented are in mean increase in learning compared to print-based instruction (which has a baseline benefit of 0) as measured in standard deviations. These are summarized in the table below.

Tasks	Print	CBT	IVD	Internet	Videotele-Conferencing
Firing	0	.42	.38	N/A	N/A
IFF	0	.42	.38	N/A	N/A
Transponder					
Altitude	0	.42	.38	N/A	N/A
Speed	0	.42	.38	N/A	N/A
Safety	---	.42	.38	---	N/A
Corridor					

Table 10. Projected Training Benefits for Training Each Cue Using Different Media

Notes: The symbol "---" means that the medium is not acceptable for the task. "N/A" means we have no empirical data available. Here, a trainer could insert his/her own estimate of benefit. In cases where multiple data are available, the closest population to the target Navy population's data are used (e.g., military, followed by adult, etc.).

3.5.2 Projection of costs.

Having developed a statement of training benefit under each training delivery option, the next step is to compute the costs of each option. We noted earlier that there are two broad scenarios in which technology may be adopted: Conversion of existing courses to technology (in which case the decision is likely to rest on whether cost savings can be realized), and creation of new training technology. In both cases, the costs of technology development will come into play. In the course conversion example, the costs of the existing course will also need to be calculated.

Costs of existing courses will need to be calculated by the trainer. In Phase I, we developed a Microsoft Access-based tool to help CNET perform these computations for existing courses (discussed in section 4).

To compute technology development costs, there are two sources of data: One is industry norms, the other is organization-specific data. Industry norms exist on how much different hardware and software costs, labor rates for different categories of professionals, and how many hours of each professional are required to develop how many hours of instruction on different platforms. Therefore, industry norms could be used exclusively to compute how much it would cost to develop different types of training systems. In our work with CNET, we learned that the Navy works through different contract vehicles where equipment purchases and labor rates are specified contractually. Therefore, the Navy uses these assumptions in cost estimating. The unknown variable is still how many professional hours are required to develop the technology. Again, industry norms could be used. On the other hand, the Navy may, when working with a consistent set of contractors, develop a stable estimate of how many labor hours those particular contractors require to develop technology. The Navy could use those estimates, the industry norms, or a mix of the two. Because there is uncertainty in costs (as well as training benefit), it is useful to use cost ranges, as well as precise numbers, to allow for imprecision in the estimation process. This will also support later sensitivity/"what if" analyses.

3.5.3 Conduct cost-benefit analysis.

We now show how we can conduct a cost-benefit analysis using the benefits computation and the costing. For benefits, we will only use those media for which we have data. For costs, we will use some rough estimates supplied to us in our work with CNET. CNET works with four levels of interactive courseware. The second level of ICW (which they call 1B) is a graphics presentation with text. These will handle all the IFF cues except the safety corridor which requires a high fidelity simulation. The fourth level of ICW (which they call 3) is a high fidelity simulation. This will handle the safety corridor.

Cost estimates to convert an hour of instruction to these two levels of ICW are \$2500 and \$8000, respectively. These costs do not include requirements and task analysis, video or audio production (which there is likely to be some), development tools, and media distribution. For purposes of our running example, we will assume that the costs of \$2500 and \$8000 represent the total costs of building the training technology per cue. Therefore, we can summarize the costs and benefits of each technology option, compared to a baseline of existing print-based instruction, which has both an additional cost and benefit of 0.

Print

Cues	Benefit	Cost
Firing	0	0
IFF Transponder	0	0
Altitude	0	0
Speed	0	0
Safety Corridor	---	---

Table 11. Projected Costs and Benefits for Training Each Cue Using Print

ICW Level 1B (low level CBT)

Cues	Benefit	Cost
Firing	.42	2500
IFF Transponder	.42	2500
Altitude	.42	2500
Speed	.42	2500
Safety Corridor	---	---

Table 12. Projected Costs and Benefits for Training Each Cue Using ICW Level 1B

ICW Level 3 (high level simulation-based CBT)

Cues	Benefit	Cost
Firing	.42	8000
IFF Transponder	.42	8000
Altitude	.42	8000
Speed	.42	8000
Safety Corridor	.42	8000

Table 13. Projected Costs and Benefits for Training Each Cue Using ICW Level 3

Hybrid Technology: Level 1B for all cues except corridor, Level 3 for corridor

Cues	Benefit	Cost
Firing	.42	2500
IFF Transponder	.42	2500
Altitude	.42	2500
Speed	.42	2500
Safety Corridor	.42	8000

Table 14. Projected Costs and Benefits for Training Each Cue Using Hybrid Technology

The above tables do not represent the continuing costs of conducting print-based instruction. These costs only represent the additional development costs. If course conversion was being conducted, then the ongoing support costs for delivering print-based instruction as well as maintaining and updating technology would have to be included. In this way, trainers could compute whether the additional cost of developing technology under different options would ultimately pay for itself (CNET identified a five year "break even" period as a desirable goal).

We illustrate this by example: The cheapest cost of course conversion that captures all the learning objectives is the hybrid technology with a cost of \$18,000. Let us assume that it will reduce training time by 30% (consistent with findings by Orlansky and String, 1979 and Fletcher, 1991). Let us assume that it costs \$20,000 per year under current training. For purposes of this example, we will assume that inflation is 0 and that all costs are tied to training time (there are no fixed costs that occur regardless of how long students train). Therefore, it will cost \$14,000. The following table illustrates a five year cumulative dollar cost projection for both course conversion to CBT and current training method:

Year	Current Approach (cum \$)	Conversion to CBT (cum \$)
1	\$20,000	\$32,000
2	\$40,000	\$46,000
3	\$60,000	\$60,000
4	\$80,000	\$74,000
5	\$100,000	\$88,000

Table 15. Projected Five Year Cumulative Costs for Maintaining Current Course Format and Converting to Technology

As can be seen from the above table, the break even point occurs in year three and by year five, the technology has saved a total of \$12,000.

3.6 Conduct tradeoff analyses.

It is clear from the above cost-benefit tables that the hybrid technology dominates the ICW level 3 option as it delivers the same training benefit at reduced costs. However, the other options are less clear. In all cases, money can be saved but a loss occurs in training benefit. This is where the benefit of the INKS-based operationalization of learning objectives comes in. INKS provides a mechanism for analyzing not only what topics will or will not be trained by each technology option, but also what knowledge and skills will or will not be trained. This is illustrated using our running example.

ICW level 3 is the only medium that trains the safety corridor. In our IFF example, recall we had the following INKS-based inference rules (procedures) associated with the IFF cues:

- a) If the aircraft is firing at you, treat as enemy.
- b) If the aircraft is not firing at you and its IFF transponder signals friendly, treat as friendly.
- c) If the aircraft is not firing at you and its IFF transponder has no signal, then use a two out of three rule for the remaining cues to determine whether to treat aircraft as friend or enemy (assuming that there is a correspondence between altitude, speed and safety corridor and what friendly vs. enemy planes would do).

Using this knowledge, we can see that if we opt for ICW level 3, all rules can be taught using practice on the simulation. If we opt for ICW level 1B, we cannot teach safety corridor. Therefore, we can still teach the rule about enemy firing, we can teach the rule about IFF transponder, and we can teach the case where speed and altitude both signal friendly or both signal enemy since these would equal the two out of the three necessary to make the determination of IFF. What cannot be taught is the case where altitude and speed conflict with each other since safety corridor is not available as a tie breaker. The trainer would have to determine how important that scenario is in order to determine what tradeoff to make.

Finally, if we opt for print-based media, we can teach all the cues that are teachable with ICW level 1B. This sets up an interesting tradeoff problem. Assuming we eliminate the ICW level 3 option because it is dominated by the hybrid option (same training benefit as the ICW level 3 option at a lower cost), we have three remaining options: retain the print-based instruction, use ICW level 1B, and use the hybrid technology.

Print vs. ICW level 1B is a case where both media meet exactly the same learning objectives. The main difference is that ICW level 1B produces greater learning gains but for a higher cost. A decision maker would have to make the choice of whether it was worth the investment to produce these higher gains. This decision may be driven by whether the organization is satisfied with current achievement levels of trainees who receive the print-based instruction. ICW level 3 vs. the other two is a case where additional learning objectives are met, but at a higher cost. Here, the tradeoff is whether meeting this learning objective is worth the estimated \$8000 it would cost to build the technology. Finally, our method also allows for innovative solutions in cases of limited resources. For example, the decision maker could opt to build technology for the

safety corridor cue but retain print-based instruction for the others. This option would cover all learning objectives, although the learning objectives other than safety corridor would be covered via the medium (print) that produces the least amount of learning.

We cannot “solve” this dilemma in the abstract. In order to arrive at the best decision, the organization would have to determine how satisfied it was with current achievement levels so that it could determine the added value of additional achievement that technology could offer. It would also need to prioritize its learning objectives because these priorities also influence the value of increased learning. Once the projected value of the increased learning was established, the organization could determine whether the value realized was worth the investment required. Section 3.6.1 outlines a generic tradeoff methodology that describes how to establish these values and then trade them off against costs.

3.6.1 A generic tradeoff methodology.

The design of a multimedia trainer is characterized by one or more scarce resources (e.g., FY1999 “then-year” dollars, FY1995 person hours) that have to be “spread” across many components of the multimedia trainer in order to achieve one or more benefits of training. Each component needs a varying amount of the scarce resource in order to provide some needed return, but typically, insufficient resources are available to fund all of the competing components at the desired level. In evaluating the worth of the components, measures of training benefit may be focused along a single dimension or attribute, or they may be so complex that a “multiattribute” model of training benefits is needed. In order to solve such a multimedia design problem, we need an algorithm that insures that an optimal (or nearly optimal) amount of training benefit is achieved for any specified resource level of each component.

First, we will consider the simplest case - *a single scarce resource needs to be allocated across a finite number of multimedia components having a single measure of training benefit.* We could model the multimedia components as continuous functions in which the independent variable is the resource requirement and the dependent variable is the benefit returned. This would typically be solved by a nonlinear programming algorithm requiring that the function be concave (e.g., first derivative continuous and positive but monotonically nonincreasing). However, we have found that very few people think of their system components in this way; rather, they identify a finite number of discrete funding points, called “levels”, for each multimedia component. Typically, each funding level has very compelling rationale for what is included in the component at that point and what is not. In the simple case, we will model each component as having a finite number of funding levels, each defined in terms of the scarce resource required and the benefit returned.

This model of a multimedia trainer with discrete funding levels can be viewed as a table (see Figure 1) in which each row represents a multimedia component, and columns represent the funding levels within a row. The names of the components are identified on the left. The column labeled “1” defines the first level of funding; this funding level is the minimum acceptable level of funding for each component. In a zero-based analysis, the funding requirements in each component would be zero. However, it often does not make sense to do a

zero-based analysis for a system design, in which case, this minimum acceptable must be defined in an agreed upon manner by the trainers and technologists. Each succeeding level (or column) in a specific row of the table defines a funding point which is more costly than the previous one. In the simplest formulation, each succeeding level includes all previous levels. Note, as shown in this figure, there is no requirement that each component have the same number of funding levels. The rightmost level in each row represents the maximum amount of funding considered for the component in question. We allocate our resources among the rows; recall that there is not enough resource to fund the rightmost levels for all components. At a minimum, there must be enough of the scarce resource to cover the first levels of all of the components or no feasible solution will exist.

Multimedia Components	Level 1	Level 2	Level 3	Level 4
Textual Material	Basic Text	+ Multi-screen Text	+ Interactive Text	
Graphical Material	Basic Graphics	Interactive Graphics	Complex "CAD" Graphics	
Video Material	None	Limited Video	Large Amount of Video	+ Graphic & Text Overlay
Audio Capabilities	None	Voice & Music Output	+ Voice Input by Student	
Animation Capabilities	None	Basic Animation	Interactive Animation	Student-Designed Animation
Testing Capabilities	Basic Multiple Choice	+ Randomized Questions	+ Review of Mistaken Material	+ Diagnosis of Mistakes

Figure 1. Resource Allocation Matrix

A solution to this multimedia design problem can then be defined by identifying which level in each row obtains funding. The shaded boxes in Figure 1 show one possible multimedia design.

Since the scarce resource can be represented in a single dimension, we simply have to estimate how much of this resource is required to satisfy the component requirements in each level of each row. In Figure 2 we show the total resource needed to fund the component at each level in the lower left corner of each funding level. Since these numbers are defined in only one dimension, they are automatically on the same scale and can be compared directly.

Multimedia Components	Level 1	Level 2	Level 3	Level 4
Textual Material	Basic Text	+ Multi-screen Text	+ Interactive Text	
Wt = 30	10 0	15 70	40 100	
Graphical Material	Basic Graphics	Interactive Graphics	Complex "CAD" Graphics	
Wt = 40	15 0	50 85	85 100	
Video Material	None	Limited Video	Large Amount of Video	+ Graphic & Text Overlay
Wt = 45	0 0	10 25	25 50	50 100
Audio Capabilities	None	Voice & Music Output	+ Voice Input by Student	
Wt = 70	0 0	15 50	130 100	
Animation Capabilities	None	Basic Animation	Interactive Animation	Student-Designed Animation
Wt = 75	0 0	25 25	70 60	180 100
Testing Capabilities	Basic Multiple Choice	+ Randomized Questions	+ Review of Mistaken Material	+ Diagnosis of Mistakes
Wt = 100	20 0	25 15	40 50	70 100

Figure 2. Resource Allocation Matrix with Costs, Scores, and Weights

The benefits of the levels must also be estimated, typically by educational specialists and technologists. For benefits, we often do not have a readily available quantitative measure that can be used. As a result, we have to create one. An effective approach is to break benefit into two components -- a score measure for comparing levels within a single component, and a calibration measure to compare benefits across components. We will use the word "scores" to label the benefits within each component, and the word "weights" to label the benefit calibration measure across components. For ease of benefit elicitation, we typically normalize the scores so that the benefit associated with the level having the **least** value (usually level 1) is zero because it is a baseline representing the minimum acceptable funding level. In addition, the benefit score associated with the **most** valuable funding level in a component (typically the rightmost level) will be 100. Note that we could have chosen any arbitrary endpoints since they represent *relative* benefit measures. Also note that zero does not mean this baseline has **zero** benefit. Rather, it reflects benefit as measured from a **baseline** level. Similarly, a 100 does not mean that all needs are met. Rather, it reflects 100% of the benefit over baseline reflected in the model. The benefit score of a level is shown in the lower right hand corner of each cell in the matrix. At this point in time in the modeling process, these benefit scores cannot be compared *across* components. To

make such a comparison, we must now assign weights to each component row that measure the relative benefit of “swinging” from minimum to maximum funding in each component; this weight is shown at the bottom of component cell. The total benefit of each funding level is then the product of the benefit score for that funding level multiplied by the “swing” weight for that component. This total benefit is directly comparable across components. Figure 3 shows a resource allocation model with the costs, scores and weights placed in their respective positions.

The simplest prioritization rule for defining which component levels obtain funding is the one that prioritizes the funding levels by their incremental benefit divided by their incremental cost ($\Delta B/\Delta C$), typically called cost-benefit analysis. A higher benefit-to-cost (lower cost-to-benefit) ratio is better. This resource allocation algorithm assumes that the first levels of each component are funded, and then determines an “order-of-buy” by sorting the remaining levels from highest to lowest by their incremental benefit/cost ratio as shown in Figure 3. The first column shows the order in which levels are funded, with a 0 indicating that a level is in the baseline (note: the line in Figure 3 separates the baseline from the trade space). The “COMPONENT” column names the row which has the next level, while the “LEVEL” column indicates the number and name of the next level funded. The next four columns show the incremental cost, cumulative cost, incremental benefit, and cumulative benefit, respectively. We are assuming that if the third level of the first component is funded, then levels 1 and 2 are funded as well. Having defined this order of buy, we can next tally the amount of resource needed to get to each succeeding point on the priority list. There will come a point where we can afford a specific level on the list but cannot afford the next. This is where a funding line will be drawn. Everything above the line is funded, and everything below it is not.

Buy #	Component	Level	Incr. Cost	Cum. Cost	Incr. Benefit	Cum. Benefit
0	Textual Material	1 Basic Text	10	10	0	0
0	Graphical Material	1 Basic Graphics	15	25	0	0
0	Video Material	1 None	0	25	0	0
0	Audio Capability	1 None	0	25	0	0
0	Animation Capability	1 None	0	25	0	0
0	Testing Capability	1 Basic Testing	20	45	0	0
1	Textual Material	2 + Multi-screen Text	5	50	21	21
2	Testing Capability	2 + Randomized Questions	5	55	15	36
3	Audio Capability	2 Voice & Music Output	15	70	35	71
4	Testing Capability	3 + Review of Mistaken Material	15	85	35	106
5	Testing Capability	4 + Diagnosis of Mistakes	30	115	50	156
6	Video Material	2 Limited Video	10	125	11	167
7	Video Material	3 Large Amount of Video	15	140	11	178
8	Graphical Material	2 Interactive Graphics	35	175	34	212
9	Video Material	4 + Graphic & Text Overlay	25	200	22	244
10	Animation Capability	2 Basic Animation	25	225	18	262
11	Animation Capability	3 Interactive Animation	45	270	26	288
12	Textual Material	3 + Interactive Text	25	295	9	297
13	Audio Capability	3 + Voice Input by Student	115	410	35	333
14	Animation Capability	4 Student-Designed Animation	110	520	31	364
15	Graphical Material	3 Complex "CAD" Graphics	35	555	6	370

Figure 3. Order-of-Buy

The results of this order-of-buy prioritization can be plotted in two dimensions, cumulative benefit versus cumulative resource as shown by the dots in Figure 4.

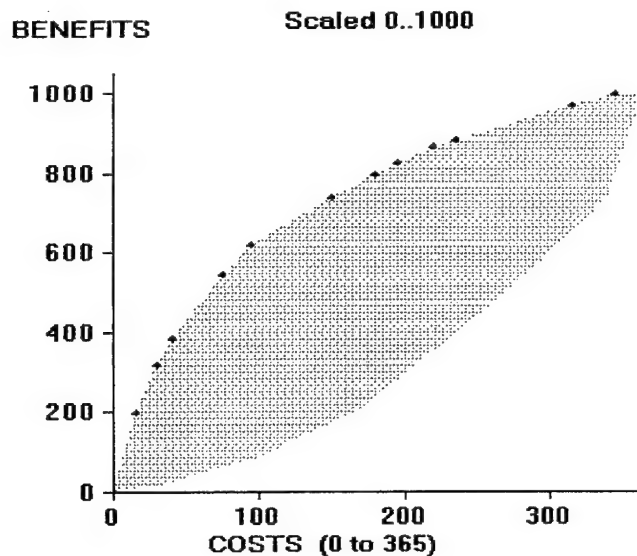


Figure 4. Benefit/Cost Plot

The football shaped region contains all of the possible funding options and is known as the Pareto space. Starting in the lower left, we fund only the minimum acceptable levels; and ending in the upper right corner, we have enough resource to fund all components fully. Our scarce resource constraint will fall somewhere between these two extremes. The funding solutions that correspond to the order-of-buy fall along a piece-wise linear upper boundary of this football, known in mathematical programming as the convex hull. This makes up what is known as the *Pareto optimal frontier* or the *efficient frontier*.

When there are multiple objectives or criteria associated with the competing components, the benefit analysis becomes more complex. For example, with conflicting criteria, a component that has increasing benefit in one criterion as we move from left to right in the matrix of levels may have decreasing benefit in another criterion. Examples of multiple objectives associated with the multimedia trade-off analysis are: training time for fastest 20% of students, training time required for at least 95% of class to pass course, and operating cost per year (including technology and staff).

There are several equally valid ways to measure and compute these benefits. For the purposes of this proposal, we will just present one. We take the criteria one at a time and develop a 0 to 100 scale for each row on each criterion. Since the criteria may conflict with each other, it is likely that the 0 *will not* be associated with the first level and the 100 *will not* be associated with the rightmost level for every criterion. This will change some of our assumptions about how the levels in our structure table are defined; however, we will continue to assume that the minimum acceptable level of the component with the least resource requirement is in the first level and that the cumulative expenditure of resources increases from left to right.

Next, we will define "within criterion" weights; we will select a single criterion, and "within" the selected criterion, we will assign "swing" weights to the rows as before. We repeat this procedure for each criterion.

Finally, we will define "across criterion" weights, one for each criterion that will determine the relative impacts of the criteria on the results. In the simplest case, we can think of these weights as the relative importance of the criteria. In the third section, we will interpret these weights in a more mathematically sophisticated manner. When these across criterion weights are multiplied by the within criterion weighted scores, we have the final benefit measure that can be compared across all component levels. This is the benefit measure that will be used in the incremental benefit/cost analysis to determine the order-of-buy.

Initially, we are assuming that levels are ordered in decreasing $\Delta\text{benefit}/\Delta\text{cost}$ order; however, there is no guarantee that this will remain the case if we change the across-criteria weights, even slightly. Therefore, whenever any of the across criteria weights are changed, the structure of the matrix must be reexamined before the resource allocation process continues. If the within criteria weights are changed, we must examine, at a minimum, those components affected by the change.

4.0 DEVELOP A COSTING TOOL FOR COURSE CONVERSION.

Purpose of Decision Aid

Currently, curriculum managers of courses for training and education have tens to hundreds of courses that they provide on a periodic basis, primarily via the traditional one-on-many lecture format. There is continuing pressure to deliver this material more cheaply without compromising the educational effectiveness provided to the student population. Unfortunately, there is a substantial cost for converting lecture material with overheads to even the most basic interactive courseware (ICW) with a single thread for the student to follow at her own pace. Converting to one of the more enhanced interactive courseware options with multiple branching for the students, adaptive testing and presentation, sophisticated simulations, and virtual reality requires even greater investments. Competing with interactive courseware is a less sophisticated video teleconferencing capability that allows the instructor to provide the lecture material to multiple places simultaneously. This format primarily saves travel time for the students or the instructor; the up front cost primarily involves hardware and software for delivering the course to multiple places. The potential savings for interactive courseware are far greater; the instructor can be replaced to some degree by the courseware, travel costs can be reduced or eliminated, and the students can use the courseware anytime and anyplace, providing greater flexibility and reduced time for many of the students as well. Finally, slower students can proceed at their own pace, making it possible that fewer students will be setback or dropped for academic reasons.

Phase I Prototype Activities

As part of the phase I effort, RDC developed a prototype decision aid for examining the relative cost of conducting a given course using the standard lecture format versus one of four Interactive Courseware (ICW) delivery options and a Video Teletraining (VTT) option. The user of such a decision aid would be curriculum managers. These managers are either trying to save money while maintaining a given level of training effectiveness or enhancing training effectiveness while maintaining a fixed level of spending. Our prototype only deals with the first objective, saving money while maintaining effectiveness. The purpose for this prototype was to obtain feedback from curriculum managers on what features they needed in such a decision aid.

The four types of ICW were based on the military handbook for ICW: (1A) linear video presentation with minor text; (1B) linear graphics presentation with minor text; (2) medium simulation with computer managed instruction; and (3) high level simulation permitting a high level of student interactivity, extensive branching capability, maximum remediation opportunities, and real time event simulation. A summary of the features for these ICW options is shown in the table below. The estimated costs to convert an hour of lecture and other material to ICW format are \$2000, \$2500, \$4500, and \$8000, respectively. These cost estimates do not include requirements and task analyses, video or audio production, development tools, or media distribution.

Capabilities	ICW 1A and 1B	ICW 2	ICW 3
Interactivity	Low	Medium	Extensive
Sequence Control	Low	Medium	Extensive
Simulation	None	Simple Processes	Complex, Real Time
Branching	Low	Medium	Extensive
Remediation	None	Medium	Extensive
Feedback	Low	Medium	Extensive
Management System	None	Medium	Extensive
Gaming	None	None	As requested
Video	Basic	Multimedia	Multimedia
Text	Yes	Yes	Yes
Graphics	Yes	Yes	Yes
Audio	Yes	Yes	Yes

Table 16. Capabilities of Different Levels of ICW

The prototype aid computes development costs, delivery costs and travel costs for both current course delivery and the ICW/VTT options. The development of ICW or VTT will generally reduce travel costs and some delivery costs; other delivery costs (e.g., communication costs) may go up. These costs were estimated for a five year time horizon.

The prototype of this decision aid developed by RDC during the phase I SBIR effort used Microsoft's ACCESS database management software with a Visual Basic user interface. This

prototype provides the basic functionality needed by a curriculum manager, but is a very simple version of the ultimate version of the decision aid that is needed by a curriculum manager.

The user can enter information about a given course concerning the numbers of students and instructors per offering, the length of the course, the number of offerings per year, the travel associated with the course, the fixed, and variable costs associated with the course. The software prototype then provides a yearly cost summary of (1) continuing the current approach to the course offering, (2) converting to various ICW options for providing the course and (3) using video teleconferencing to provide the course. This cost summary shows whether the development costs for the ICW or video teleconferencing provide sufficient cost savings over a five year period to provide savings over and above the development costs.

5.0 TEST THE TOOL ON CNET SUPPLIED COURSES.

We tested this prototype on four CNET courses:

1. Basic Submarine Torpedo Supervisor
2. Advanced Electronics and Maintenance Techniques
3. Gun Fire Control System, Mod 8/10
4. Type A1, FC specific electronics training

This prototype was demonstrated to managers of education and training courses for the Navy. After the demonstration, these managers furnished us with data necessary for computing the costs of converting the courses. Such data are described in Section 4.0 above, and include variables such as the number of trainees per course, travel costs, instructor costs, etc.

Once we completed our analyses, we returned to CNET. The course of highest priority to them was the Basic Submarine Torpedo Supervisor course. Therefore, the demonstration of the tool's analysis of CNET supplied data focused on this course. After some initial data exchange and verbal discussion, the prototype generated recommendations, based on cost savings, for which technology medium to use in the course conversion. These recommendations were the same as the conclusions that CNET had reached when they performed their own independent analysis. (The results of this analysis are actually shown in Figure 17.)

6.0 DISCUSSION

The present project attempted to fill a need within the training and education communities regarding how technology is purchased and used. In practice, much technology procurement is done ad hoc without a formal analysis of what the projected training benefits will be measured against the costs involved. The main innovation offered in the present project is the methodology for operationalizing a set of learning objectives in such a way as to specify technology requirements, and in turn, training benefits that are expected from different technology options. Such a methodology allows the training community both to insure that the technology it procures will be adequate for the requirements yet not cost more than is necessary.

Because the issue of moving training from the schoolhouse to technology is such a hot issue, there are several other efforts within the Navy to develop decision making/analysis approaches for using multimedia technology for training. We present illustrative projects and highlight the differences and, hopefully, value-added to our approach. In these discussions, we present the caveat that our understanding of all the work being done may be incomplete as efforts continue to be ongoing.

6.1 Differences between our approach and one being developed by CNET

In our work with CNET, we learned that they are interested in converting courses from classroom-based to technology-based. Their stated objective is to justify the costs of doing so by demonstrating a projected break-even point within five years of making the investment to develop the technology. CNET was less focused on developing models to predict training benefits of different training technologies. They correctly observed that the literature reporting training benefits tended to show variable results. Therefore, they feel less comfortable using such inputs in their analyses.

On the other hand, we know of no formalism within their work that specifies which technology to convert a course into (e.g., CAI, ICW, VT). This appears to be done as a matter of professional judgment or perhaps driven by cost factors.

We believe our framework provides an analysis method for selecting which media to use for training a course. The framework provides an empirical justification for projecting training benefits of those media, even if such benefits may have to be expressed as a projected *range* of benefits as opposed to a precise benefit. However, cognizant of the imprecision in the estimation process, we provide two remedies. First, we discuss sensitivity analysis to explore different assumptions regarding those benefits in a cost-benefit analysis. Second, we discuss the use of data collection and Bayesian updating tools to allow the users to collect training benefit data on their own population of students, courses and technologies, which we believe will lead to more reliable and stable projections of training benefits.

We cited earlier, however, that there was a second scenario in which training technology may be developed, namely development of training for new technologies/platforms/requirements, etc. In such cases, an existing successful course is likely to be unavailable. As far as we can tell, the CNET framework is silent on which training technology to use. In such cases, there is likely to be additional media not considered by their current work, e.g., embedded training, Internet-based training, Distributed Interactive Simulation, immersive virtual reality.

We believe that if the Navy is to exploit the proliferation of technologies available to deliver training, there needs to be analysis methods with a theoretical/empirical basis to help select which of these media will deliver the intended training. We believe this needs to be taken into consideration as well as costing.

We agree with comments made by Dr. Jim Young of NAVAIR that building such a theoretical/empirical framework will take years in the making and would not be responsive to the immediate needs of converting courses to technology-based training. However, the issue of what training to accompany what need (given that there are more and more options to deliver the training) is a long term problem. The present work is designed to address the immediate course conversion needs as well as provide a foundation for addressing these long term problems.

6.2 Differences between our approach and TRADAM.

The Defense Standards Workgroup has recently developed a Training Delivery Assessment Model (TRADAM). TRADAM is a fairly comprehensive analysis process that takes a training requirement and analyzes it through various steps of developing learning objectives, defining sensory cues, media selection, training system design, etc. As such, we see TRADAM as a useful methodology for addressing the need described in the previous section, namely matching future training requirements to the media most suitable for selection. As described currently, it is less detailed, although consistent with, the costing models that organizations such as CNET need for course conversion analyses.

We see our framework as highly compatible with TRADAM. Our framework stops at the point of selecting the training media, analyzing the costs and benefits of different options and then conducting a tradeoff analysis and making decisions regarding resource allocation. While our analysis would then support the design and maintenance of the technology, our framework does not prescribe how to do so. (We could extend our framework accordingly, as we are experienced training system designers. However, we see this as being beyond the scope of the SBIR topic to which we are responding.)

We believe our work enhances TRADAM in several respects. Based on discussions with Dr. Bill Terrell of NAWC TSD, we have identified two value added areas the proposed project will address. First, Dr. Terrell noted that TRADAM does not provide an analysis of how to help the student learn. In other words, media selection is derived from the sensory cues necessary to meet a learning objective. There is not a link between the media and the cognitive requirements for learning the objective. There is no empirical database for justifying the media selection. There is no methodology for specifying the mix of instruction to build specific concepts. In Section 3.3, we describe a step in our methodology, "Develop training strategy", which is missing in the TRADAM. This step occurs prior to media selection and drives that process.

A second need identified by Dr. Terrell was tools to support the implementation of TRADAM. Dr. Terrell expressed the concern over whether members of the training community would adopt TRADAM if no tools were available to help the process. A future direction our work would take would be to develop automated tools to implement our framework, which we stated, was an enhanced subset of the TRADAM.

We stated above that although TRADAM was consistent with the cost analysis requirements of technology procurement, it was less detailed than is needed by an organization such as CNET to perform such analysis. Recognizing that course conversion is an immediate need faced by the

Navy (as well as other organizations), our work is designed to support the in-depth cost analysis required for this process.

By comparing the above two ongoing efforts (CNET, TRADAM), we have tried to show that each has strengths and areas for value-added enhancement. Specifically, each approach appears to be better suited for one of the scenarios of training technology development (i.e., CNET for course conversion, TRADAM for long term training system development). The long term goal of our work is to develop a methodology and supporting tool to support both needs and enhance the ongoing work in each community.

7.0 FUTURE DIRECTIONS

The biggest benefit to the training community should come in terms of developing automated tools to simplify the types of analyses described in Section 3. The tool needs to do more than simply step the user through the complexities of the decision making process (e.g., handling on the technology-relevant data, performing cost-benefit and tradeoff computations). It is important that the tool help the user maintain continuity in the thought process. As in all training and education technology procurements, the goal is to use technology to support learning. However, it appears that technology is often bought without a formal analysis of how that technology will enhance student learning.

Our project has tried to remedy this process by creating a methodology that starts with organization-defined learning objectives. These learning objectives form the basis for developing technology requirements that will meet these objective. The cost-benefit analysis also ties directly back to the learning objectives. Tradeoff analysis presents a picture not only of monies that can be saved but also learning objectives that are impacted by that.

Below we describe the design of a more comprehensive tool that will implement our methodology while preserving the continuity of the learning objective-driven, decision-making process.

7.1 An automated tool to support our TRADAM-enhanced methodology.

Our goal is to support the both course conversion analysis and the TRADAM process. With regard to the former, we have a leg up as the Phase I system was designed to do that and was far enough along as to provide analysis for sample CNET courses. With regard to the latter, the tool will not be a one-to-one match to TRADAM (but will be a one-to-one match to our methodology) as it will omit some steps in the overall process while adding the step of developing a learning strategy.

System Architecture

The design of this decision aid contains six basic elements as shown in Figure 5. The top element controls all interaction with the user via keyboard and mouse inputs and well as the

displays on the screen. The left element maintains the various databases of the users as well as the databases for costs, technology, training effectiveness supplied with the decision aid. The two middle elements perform the processing required by the analyses and control this processing, as well as, the user interaction, database operations, and report generation. The Cost Analysis module is part of the processing element and is responsible for performing cost analysis on the course data for each of the possible course formats (Current IM, ICW-1A, VT, etc.). The Benefit Analysis module is also part of the processing element, differs only slightly in form and function from the Cost Analysis module, and is responsible for performing a benefit analysis of the course in its various formats. The bottom element contains the help database as well as provides a repository for historical data based upon usage of the decision aid over a long time period. Finally, the right element is responsible for providing hard copy reports to the users.

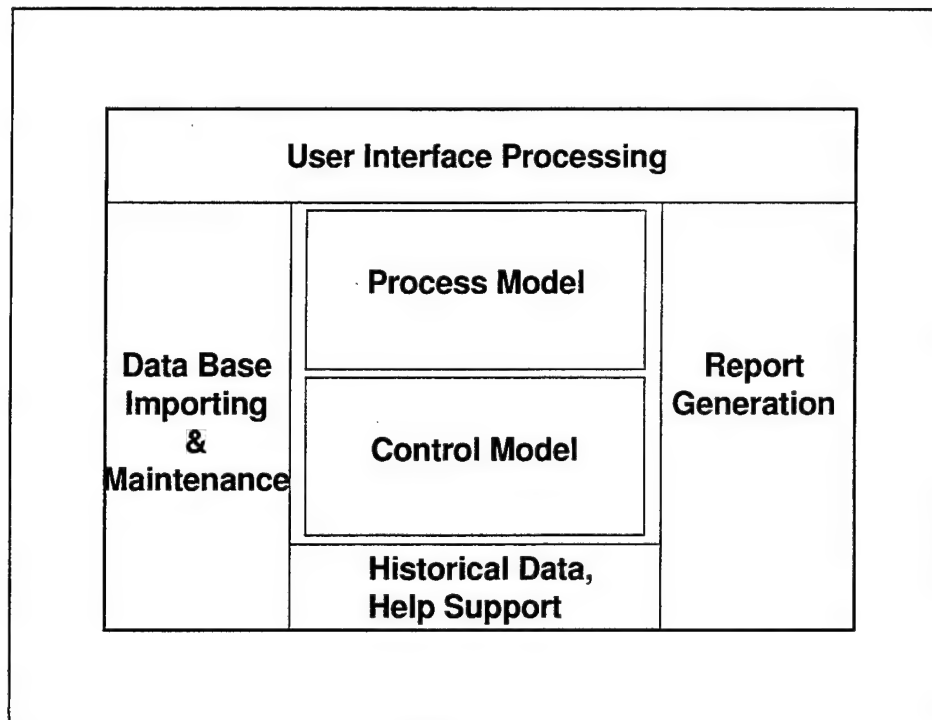


Figure 5. Design Elements of Decision Aid

The following figures and descriptive material describe samples of the system architecture as we currently envision them.

Customization of such elements as the time period and cost elements by the user:

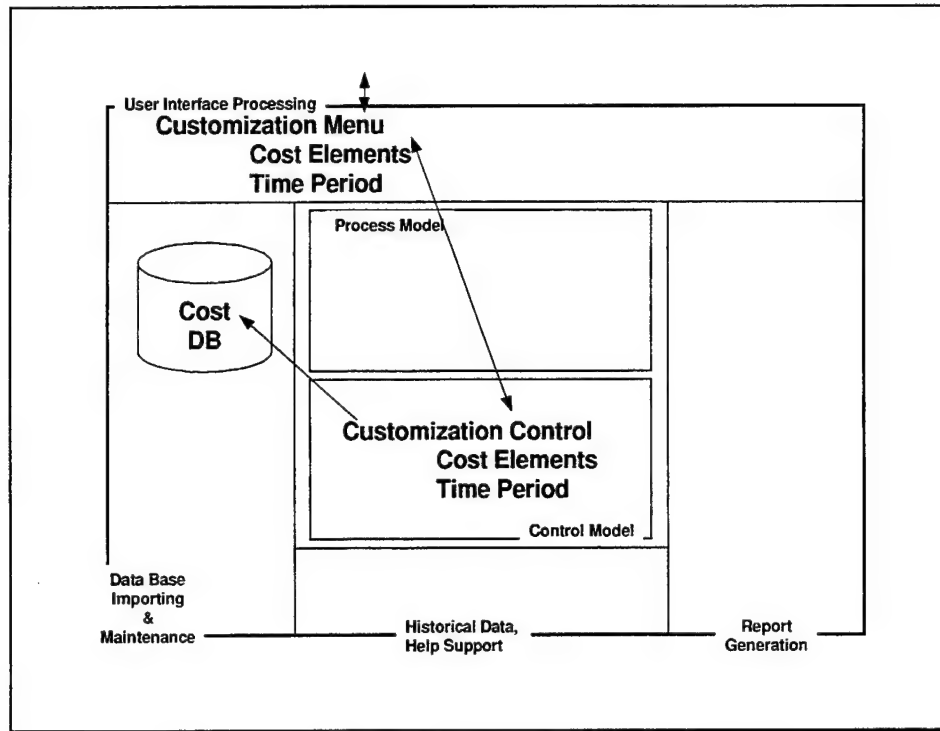


Figure 6. Customization by the User

The user shall be able to customize the decision aid based upon the relevant time periods for her organization. For example, the user shall be able to indicate that her organization keeps cost elements by hour, day, week, month, or year. In addition, the user will be able to identify certain groupings for fixed and variable cost elements. These entries will determine how the user's database is set up and will cause conversions to the default cost data base.

Personalization of the evaluation process:

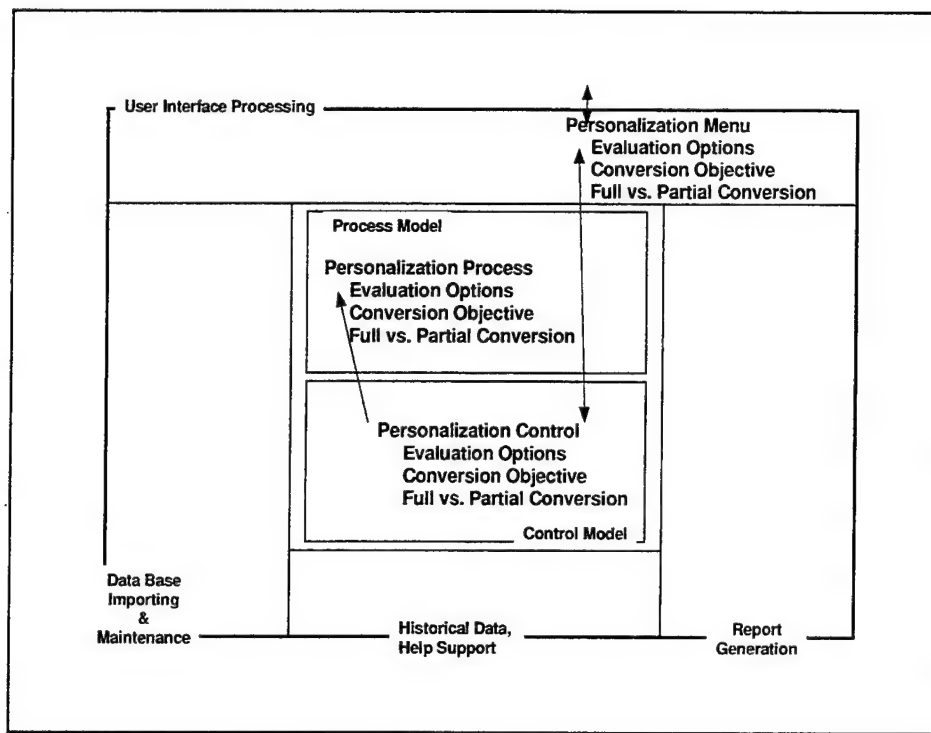


Figure 7. Evaluation Personalization

The decision aid shall permit the user to personalize specific aspects of how the analyses will be conducted. For example, the user shall be able to select whether a course will be evaluated on its own merit or whether there is a budget for converting courses and each selected course is competing for a portion of that budget. In addition, the user will be able to enter her objective; namely maximize cost savings or maximize training or educational effectiveness. Finally, the user shall be able to indicate whether all courses will only be considered for complete conversion or whether it is possible to convert portions of the courses. If the latter is chosen, the user must indicate what criteria will be used for converting portions of a course (e.g., labs may be converted before the lectures).

Personalization of the results and display visualization:

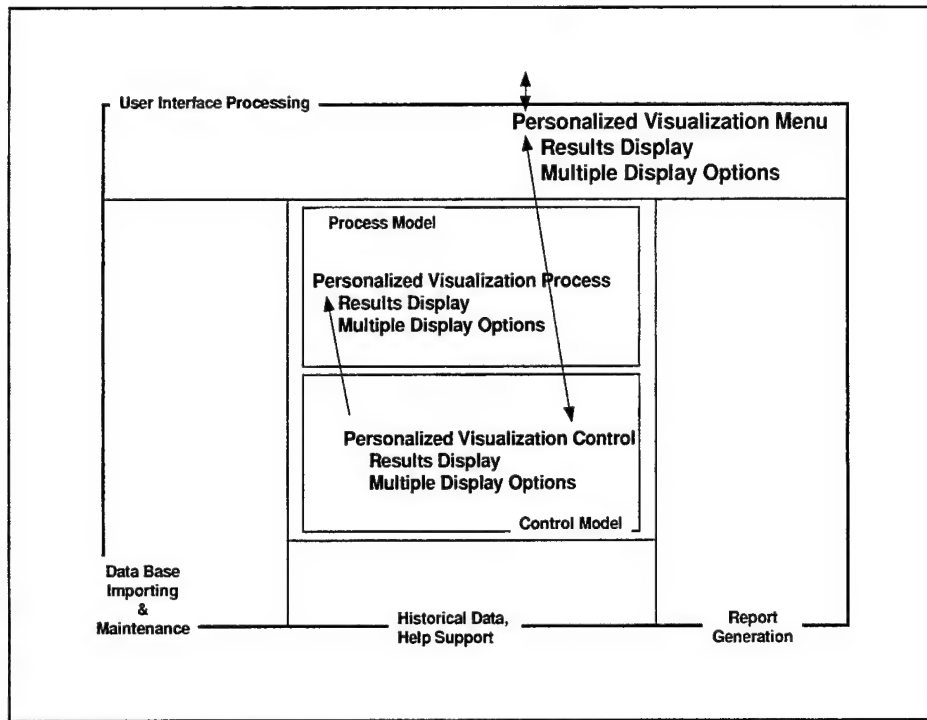


Figure 8. Personalized Visualization

The decision aid shall permit the user to personalize the visualization of results. This personalization will address the types of charts to use to display each category of results. In addition, the user shall be able to choose whether to select the display of certain combinations of results on the screen simultaneously.

Conducting a analysis of conversion options based on one of several objectives:

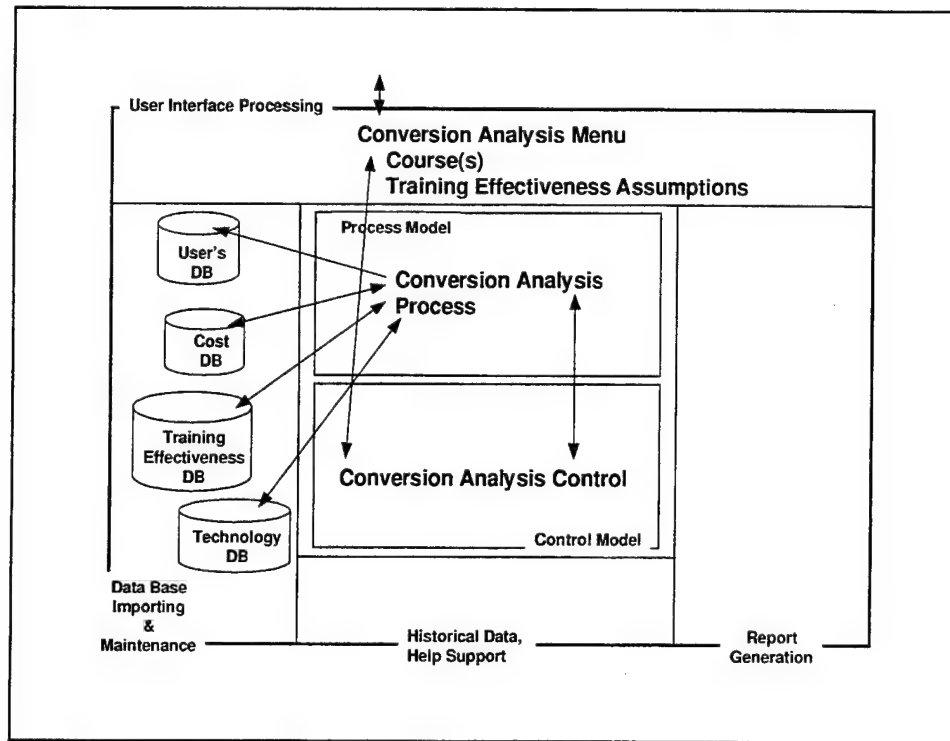


Figure 9. Conversion Analysis

The decision aid shall permit the user to enter the specific course(s) to be analyzed and the objectives and assumptions that should be made as part of the analysis. Based on these entries the decision aid shall then complete the analysis by conducting either a cost, benefit or cost-effectiveness analysis of each option as well as the current course delivery option. In addition, the decision aid shall analyze the relative training effectiveness of each option (if so instructed by the user). The training effectiveness analysis shall include training effectiveness data based upon empirical analyses conducted by the research community. This training effectiveness analysis will include Cognitive Structure Analysis using the INKS framework described elsewhere in the proposal. These results will be stored in a user database as identified by the user.

Display of analysis results to the user:

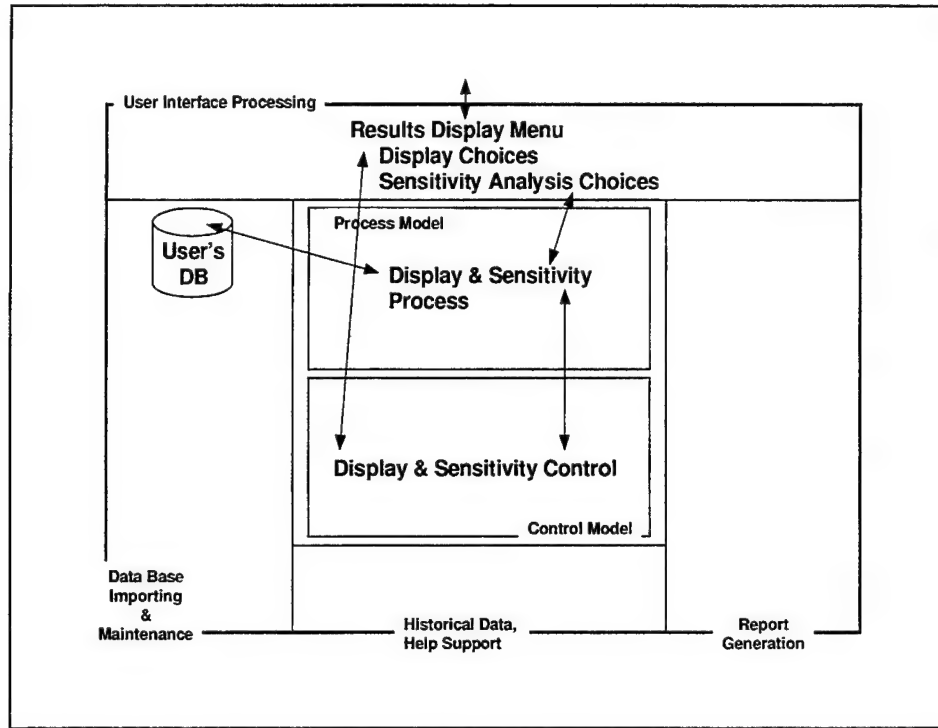


Figure 10. Display of Results

The user shall be able to obtain a display of the results of an analysis of one or more course conversions by selecting the results display menu option. The decision aid will create displays based upon the currently selected display criteria; the user has the option to change these criteria as describe above. In addition, to displaying the relative attractiveness of the competing course conversion options on whatever objectives defined by the user, the decision aid will also display sensitivity analyses of these results to specifically identified parameters defined by the user.

Provision of help to the user:

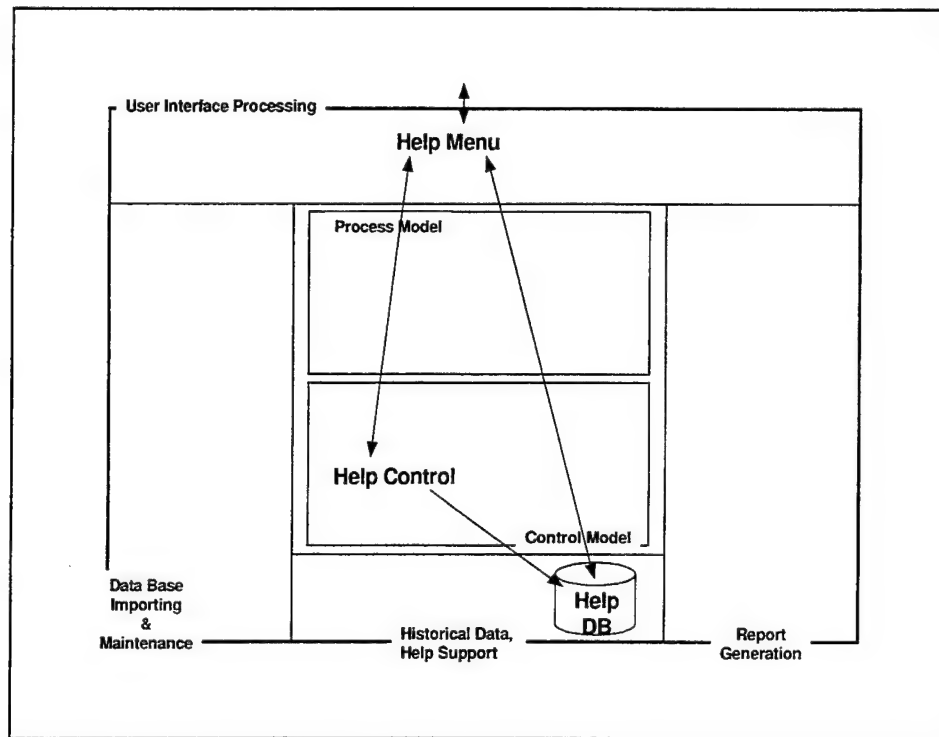


Figure 11. Help Menu

The user shall be able to obtain full on-line help. There will be a instructions on how to use each menu selection, hypertext glossary of terms and results, drill down explanation of results, and explanation of sensitivity analyses.

Database updating and creation/maintenance of a historical database:

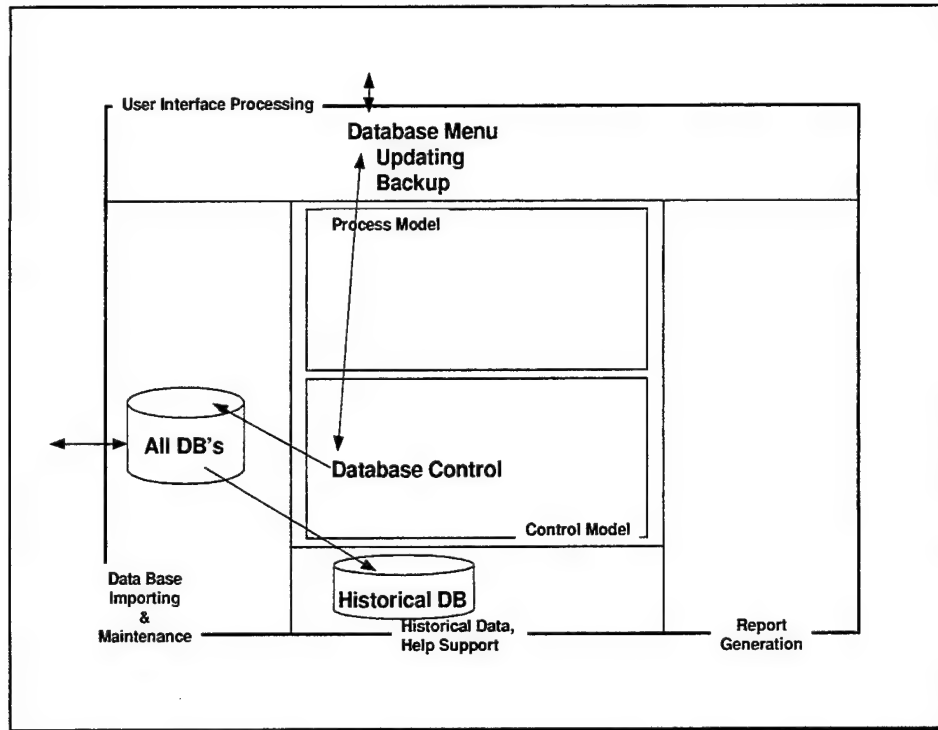


Figure 12. Database Updating and Backup

The decision aid shall permit the user to update original databases with more recent information, as well as to back up all of the databases to storage media. The user will select the database menu item and identify whether she wishes to update the databases or back up her databases. In addition, it will be possible to update the current historical database with more recent users' files.

Generation of reports for the user:

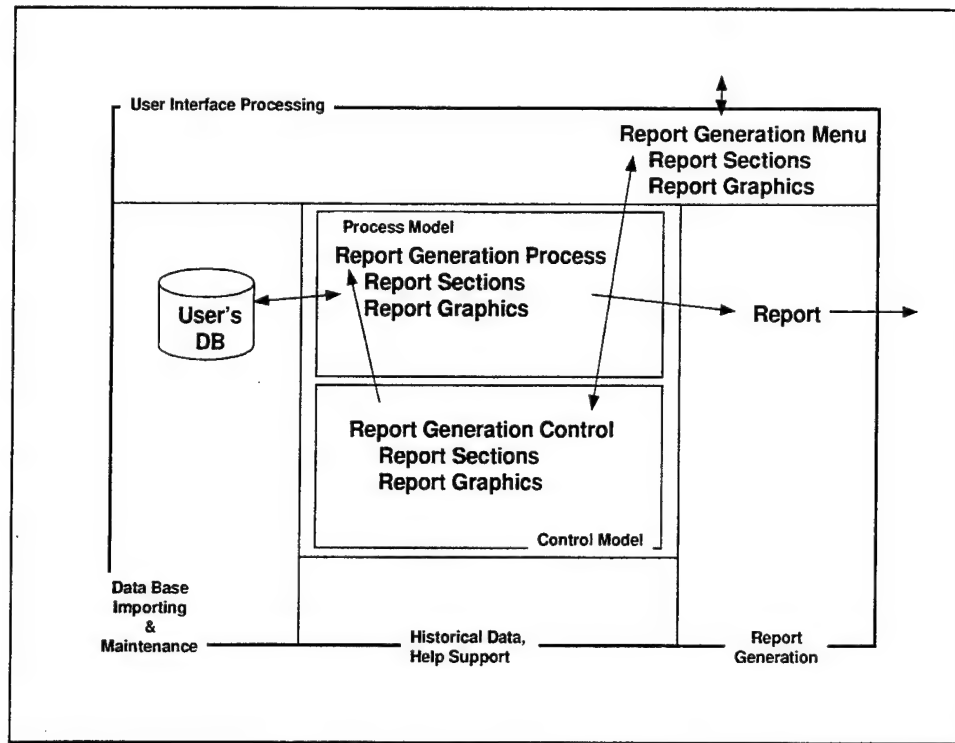


Figure 13. Report Generation

Reports that document the results of a user's analysis shall be generated when the user selects the report generation menu. The user will identify which standard report section should be included and what types of graphics (e.g., pie charts, bar charts) to include. Based on these inputs the decision aid will generate the report consistent with the data in the user's database.

Provision of historical analyses that were supported by the decision aid:

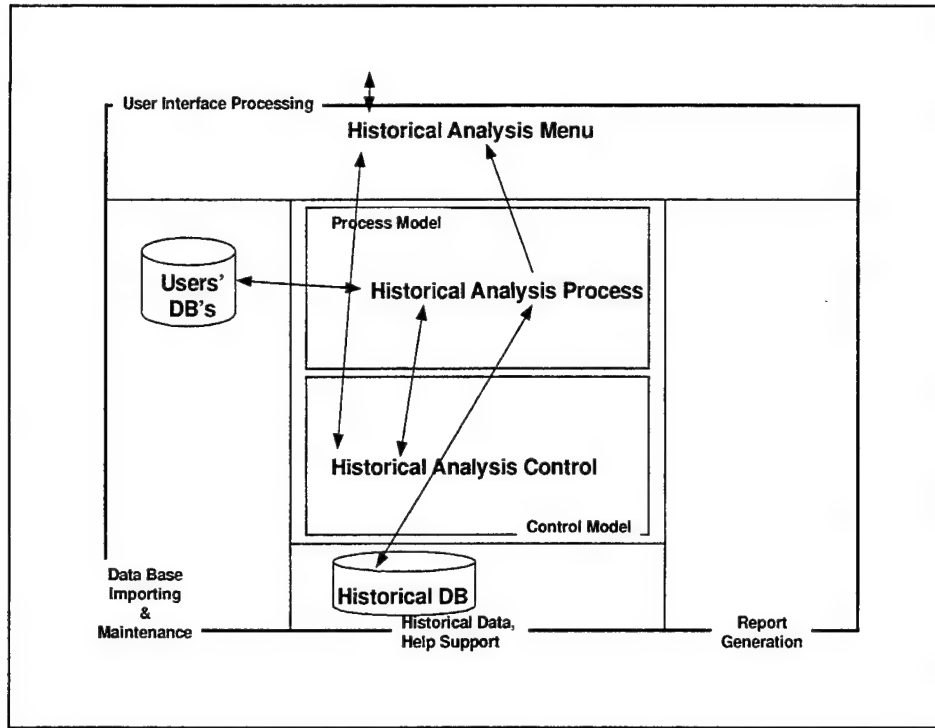


Figure 14. Historical Analyses

The decision aid shall permit historical analyses to be performed based upon a large number of uses by one or more users over a long period of time. The user selects the historical analysis menu item, identifies what elements of the historical analysis should be included, identifies which user databases are to be included, and then turns the creation of the historical analysis over to the decision aid. The historical analysis addresses what trends have been observed over the horizon of the analysis, including trends in costs and trends in changes to course conversion selections.

System Interface

When a course is initially entered into the system, there are several key pieces of information that must be entered. The course must be identified by a unique name such that it can be retrieved at a later date. The information necessary for performing the cost analysis is entered

General Questions about the Course

ID: 81

What is the number of offerings of this course per year? Nc

What is the average number of students that take the course each offering? Ns

What is the average number of students who drop out of this course due to academic reasons? nF

What is the average number of instructors that teach this course each offering? nI

What annual inflation rate for course costs do you want to use?

What % of total trainee population will take this course? q

Figure 15. Sample Input Prompts

through a series of screens.

The screens prompt the user to enter data through a series of questions about the course.

Most of these questions are very direct and difficult to misinterpret. Some of the data will be known ahead of time, such as the cost for someone to teach the course. Other data will not be concrete and instead need to be estimated, such as the cost for developing the software necessary to

convert a lecture to a CBT. However, industry standards should exist for most of these values and can be stored and modified in the Database Management module. Thus, the system can use values which can be stored and modified in the Database Management module. The system can use default values or the user can override these numbers if they have more accurate estimates.

The data necessary to perform the course benefit analysis is entered in a similar fashion. The system prompts the user (usually an SME or similarly qualified person) to break the course down into a series of learning objectives. Each objective is broken further into a series of components and their INKS representation. Through a series of check boxes, the system then prompts the user to detail the experiential breakdown of these components, be it audio, video, low fidelity, high fidelity, mathematical, temporal, spatial, etc. By breaking the objective components down into their experiential representation, the system can determine the type of media the course requires to teach the students. For example, if a course objective component had an experiential representation consisting of audio, visual, temporal, spatial, and high fidelity, it may indicate to the system that a VR chamber is necessary to teach the course objective. However, a visual, low fidelity requirement may indicate a simple picture. The system then compares this information to the target student population's profile for learning methods, and a course benefit analysis is made. This course benefit analysis will supply the user with the characteristics of the format or formats necessary to teach the course. The profile of the target student population is not input directly by the user. Instead, he chooses from a menu of profiles already in the system. There is also the option for the user to modify these existing profiles, as well as input new ones as necessary. However, these are done separate from the course analysis.

The help offered will be context-sensitive so that the user can query a particular button or question that is on the screen and see the actual results. For example, querying a bold button in a word processor gives the user a brief explanation of what actions the button performs. Similarly, querying a question in the tool will result in a more detailed explanation of what information is being sought. Context-sensitive help will increase user productivity by increasing understanding of the tool and how to use it.

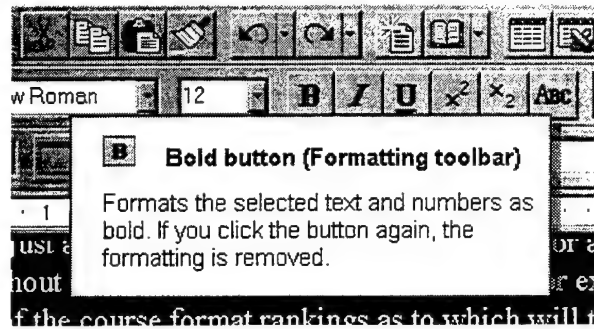


Figure 16. Context-sensitive help

The results of the analyses can be viewed in several formats. The graphical representation consists of a 2-dimensional cost vs. time bar graph for the cost analysis, where each line will represent a particular course format. A bar graph displaying the relative benefit for each of the possible course formats shows the results of the benefit analysis. A scatter plot showing the training benefit vs. cost for a specified period of time displays the results of the cost-benefit analysis. By examining this chart, the user will be able to determine the optimal course format that fits under their financial constraints.

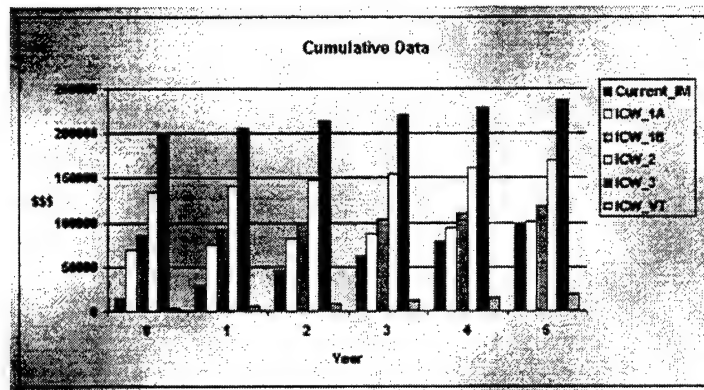


Figure 17. Graph of Cost Analysis

As was previously mentioned, one of the benefits of our architecture is the interactive analysis that it allows. When the system performs a course benefit analysis, it presents the user with a list of features of the course system requirements. This presentation is modifiable so that the user can set certain constraints. For example, if there is no way the budget will allow for a VR chamber, then the user can downgrade the allowable system features. The program will then go back and determine which of the objective components are no longer satisfied and present a list of them to the user. It will also present the user with the course objective or objectives affected and a brief explanation detailing why each objective is no longer possible as originally described by the user. Armed with this tool, the user will be able to customize the course to maximize the benefit to the student population while staying within the financial and physical constraints of the course.

7.2 Potential Research Questions Suggested by Our Framework

There are still be several areas of further R&D that could be performed. First, the biggest weakness in the proposed framework is to project training benefits given, the topic matter being taught, and the media selected. As we have noted earlier, literature consistently shows that technology can enhance learning achievement or reduce training time. We also hypothesized that training organizations would achieve more stable benefits predictions if they collected data on their own trainee populations, courses taught, and technologies used. While there will always be such variability, we believe this can be reduced. Clearly, an area of future R&D is to collect data against this hypothesis. The benefit for an organization in doing so is to build an experiential base of training technology usefulness.

Part of this R&D effort could focus on the specific analysis provided by the INKS framework compared to other analyses suggested by other frameworks. For example, our methodology uses INKS and a combination of sensory cues to develop a learning strategy to select training media. TRADAM relies more on a sensory cues analysis derived from learning objectives analysis. CNET uses professional judgment. Each of these three methods (plus others) could be pitted against each other. A study might involve taking different subject areas (to test robustness of the methods) and performing a media selection analysis for each. Groups of trainees would be selected based on the media recommended. Training time and performance could be measured to determine which method offered the most effective media selection.

Another area touched upon in our framework was inclusion of student population characteristics in the training strategy selection process. There is considerable work in learning styles/learning disabilities that offer input as to what training media may be most effective. We also touched upon experience and aptitude as relevant factors. There is considerable room for further research in exploring these individual difference variables in the use of training technology.

Related to the issue of including student parameters in the selection process is assessment of student learning. One of our parameters is student experience. This could include, not only prerequisite courses taken, but also proficiency achieved in those courses (which might also be dependent upon aptitude). Linking assessment tools to the media selection process could provide useful input regarding a student's baseline knowledge which in turn would develop the training strategy. We are currently working on a Phase I SBIR project sponsored by NAWC TSD to develop assessment tools for complex cognitive tools. Assessment is an area of specialization for RDC (we were retained by the Point Pleasant School District in New Jersey to help them develop their assessment framework based on our INKS model). We envision such assessment tools as ultimately integratable into our proposed tool.

8.0 POTENTIAL COMMERCIAL APPLICATIONS OF THE PRESENT WORK

The present project was sponsored under the Small Business Innovation Research program. A goal of this program is to sponsor R&D activities that result in commercial products and services.

We believe that the proposed work will have market potential both for the Federal Government and the private sector. Currently, there is an explosion in the development of multimedia technologies. However, the development costs for such technologies are great due to the richness of the modes of presenting information. We believe that not all training tasks require full multimedia technology to be effective. However, trainers do not have a methodology for making tradeoffs of available technologies against resources (both training time and money to procure). We believe a tool that assists in making these decisions would have commercial potential.

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